PATHOGENICITY OF *Fusarium oxysporum* f. sp. *Strigae* STRAINS ON *Striga hermonthica* (Del) BENTH INFESTING MAIZE (*Zea mays* L.) AND MAIZE PERFORMANCE IN SIAYA COUNTY, KENYA.

BY

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SCHOOL OF PHYSICAL AND BIOLOGICAL SCIENCE

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DECLARATION

I hereby declare that the material contained in this thesis is my original work and has not been presented for a degree in any other university. All sources of information have been acknowledged by means of references and citation.

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DEDICATION

This thesis is dedicated to my daughters Laura and Megan.

ABSTRACT

Striga hermonthica weed is the most widespread and noxious species that parasitises many economically important cereal crops including maize (*Zea mays* L.) in sub-Saharan Africa. *Striga* is also called witchweed in the family Orobanchaceae. *Fusarium oxysporum* f. sp. *Strigae* is a fungus of the genus *Fusarium* that causes fusarium wilt disease on *S. hermonthica.* Most control methods against *Striga*; chemicals, cultural and resistant maize are expensive, ineffective and toxic to environment hence need for a locally available, cheaper and environmentally friendly biocontrol method. Despite the existence of various control methods, the weed infestation continues to persist causing low yields in maize in Siaya County leading to poverty and hunger. There remains exigent unanswered questions regarding efficacy of local *Fusarium oxysporum* strains on *Striga* weed control and their effects on agronomic properties of maize in Siaya County. No research has been tested under field conditions on response of local strains of *Fusarium* on *Striga* infestation for local maize and to reveal their effects on growth and yield of maize in Siaya County. The purpose of this study was to determine the efficacy of five *Fusarium oxysporum* strains in controlling *Striga* weed to improve maize productivity in Siaya County. The objectives were to determine the efficacy of five pathogenic *Fusarium* strains on *Striga* infesting maize fields and to determine the effects of *Fusarium* strains infection on *Striga* on growth and yield of maize grown in Siaya County during the long and short rain seasons of 2013. Five different *Fusarium oxysporum* (FK) strains were coated on the seeds of susceptible local cultivar of Kenyan maize; "Rachar" before planting in three farm sites and a parallel control where the maize seeds were planted without *Fusarium* strain treatment, which was also replicated in the three farm sites. A complete randomized block design was used where three replications were used at each site. Data was collected between week 4 to 10 on *Striga* emergence, counting 15 cm radius around tagged maize plants and infection rates; as a percent of infected *Striga*, maize plant height (cm) from base height to youngest leaf apex, number of leaves; counting number of all leaves per tagged maize plant. Stover, cob weights (g) and grain yield (ton ha^{-1}) were determined at week 14. Statistical analysis was carried out using SAS 9.1 software using ANOVA at $P \leq 0.05$. Significant means were separated by Fishers $LSD_{(0.05)}$. The soil characteristics of the three sites varied based on geological coverage. All local *Fusarium oxysporum* (FK) strains significantly decreased *Striga* emergence ($P \leq 0.05$) to a mean of 3.7 for FK3 and a mean of 4.8 for FK5 strain. FK5 had the highest *Striga* infection rate ($P \leq 0.05$) at 77.4%, FK3 had 61.3% both at Sagam site short rain season while the lowest rates were Bar Olengo sites with FK4 at 14.2% and FK2 at 12.7% during the long rain season. There was significant higher cob weight ($P \leq 0.05$) and yield ($P \leq 0.05$) in FK3 and FK5 strains at Sagam site during the short rain season with control having the least cob weight and yield. FK1 and FK2 strains had the least effects on *Striga* emergence, cob weight ($P \leq 0.05$) and grain yield ($P \leq 0.05$) while FK5 and FK3 strains had highest pathogenicity in all sites hence are good candidates for adoption based on their performance by farmers in Siaya County to improve maize yield. The significant difference in *Striga* emmergence and infection rates were due to efficacy of FK strains to control *Striga* emmergence and hence effective infection, more so by performance of FK3 and FK5 strains, therefore most recommended strains for adoption by farmers in Siaya County. The non significant differences in maize performance were attributed to microclimatic and edaphic factors; these factors could be due to erratic rains (Appendix 2), high acidic soils with $pH<5.5$; a minimum requirement for maize growth conditions (Appendix 3) leading to low plant height, stover and cob weights and grain yield due to unavailable minerals for maize growth. Sagam had higher rainfall contributing to better yield. Future studies should focus on monitoring of edaphic and climatic conditions to elucidate the non significant differences among the *Fusarium* strains in maize agronomic properties and integration of FK strains with other methods of control for more effective *Striga* control in Siaya County.

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ABBREVIATIONS AND ACRONYMNS

KALRO - Kenya Agricultural and Livestock Research Organization

CIMMYT - The International Maize and Wheat Center

FK -*Fusarium* Kenya

PDA - Potato Dextrose Agar

PCR - Polymerase Chain Reaction

MDGs - Millennium Development Goals

RFLP - Restriction Fragment Length Polymorphism

CEC - Cation Exchange Capacity

IPM - Integrated Pest Management

IITA - International Institute of Tropical Agriculture

Foxy - *Fusarium oxysporum*

AFLP - Amplified Fragment Length Polymorphism

NCBI BLAST- National Center for Biotechnology Information- Basic Local Allignment Search Tool

DAP - Diammonium Phosphate

PEQ - Post-entry Quarantine

Growing seasons - Long Rain and Short Rain Seasons of 2013

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CHAPTER ONE

INTRODUCTION

1.1 Background Of Study

Maize (*Zea mays L*.) is a tall annual crop of the grass family and the most important cereal in Kenya (Wambugu *et al*., 2012; Chemiat and Makone, 2015). This cereal is the staple food for over 90% of the population (Atera *et al*., 2013). Although high yielding maize varieties have been developed, most of the small holder farmers in western Kenya depend on locally produced seeds (Anjichi *et al*., 2005). Despite the importance of maize, its production is faced by a number of challenges that includes technological, policy, socio-economic, abiotic and biotic factors (Avedi *et al*., 2014; Chemiat and Makone, 2015). Grain yield in most parts of the country for the last two decades has remained as low as 1.5 t/ha, which is below the world average of 4.2 t/ha (Atera *et al.,* 2013; Kiplangat *et al*., 2013).

Numerous surveys for pathogens as possible biological control agents of *Striga* species have demonstrated a growing interest of using alternative strategies to combat this noxious weed (Schaub *et al.,* 2006; Suprapta and Khalimi, 2012). The potential for biological control of *Striga* weed has received enormous attention in the recent past (Marley *et al*., 1999; Olakojo and Olaoye, 2005; Yonli *et al*., 2005; Schaub *et al*., 2006) with most studies focusing on soil microorganisms, particularly fungi of the genus *Fusarium* in cereal crops (Ciotola *et al.,* 1995; Yonli *et al.,* 2005; Schaub *et al.,* 2006). Various fungi have been tested both for pathogenicity on *Striga* with *Fusarium oxysporum* as the most prevalent fungi associated with diseased *Striga* (Ciotola *et al.,* 1995; Kagot *et al.,* 2014). Various *Fusarium* species have been isolated from diseased *Striga* plants with success (Jumjunidang and Soemargono, 2012). *Fusarium* spp. are long-lived soil inhabitant that can survive extended periods in the absence of their host by colonizing crop debris and producing chlamydospores; dormant resting propagule. Species of *Fusarium* are among the plant pathogenic fungi which are commonly associated with rice, sugarcane and maize (Ciotola *et al.,* 1995).

Fusarium species isolated from diseased *Striga* plants in West Africa (Yonli *et al.,* 2005) have shown the potential of reducing germination rates of *Striga* by approximately 90%. Some of the *Fusarium oxysporum* isolates obtained in parts of Africa includes *Foxy* 2, obtained from Ghana (Abbasher *et al.,* 1995), isolate PSM197 in Nigeria (Marley *et al.,* 1999)

and isolate M12-4A in Mali (Ciotola *et al.,* 1995). Studies have shown that most of the *F. oxysporum* strains are saprophytic and can survive for many years in soil. These pathogenic strains of *F. oxysporum* have received much attention in the past in cereal crops (Alves-Santos *et al.,* 1999).

Identification of *Fusarium* species has been previously based on morphological characteristics. In the recent past, molecular approaches involving combination of PCR and restriction analysis (RFLP) have been widely used in taxonomic studies of *Fusarium* species (Leslie and Summerell, 2006; Tamura *et al.,* 2011). Previously, studies in western Kenya revealed the two local strains of *Fusarium oxysporum* obtained from Alupe and Kibos to have mortality rates on *Striga* weed greater than 50% but under green house trials (Kagot *et al*., 2014), hence the need for maize field trials in Siaya County. In other studies, foreign isolate of *F. oxysporum* f. sp. *Strigae* (*Foxy* 2) that had been obtained from severely diseased *S. hermonthica* in North Ghana did not show substantial efficacy in controlling *Striga* weed in western Kenya (Avedi *et al.,* 2014) yet was highly effective in North Ghana. These tremendous efforts have been supported by characterization (Kagot *et al*., 2014) and diversity among pathogenic strains of *F. oxysporum*. However, none of the studies evaluated the effects of locally isolated FK strains on *Striga* weed under field conditions as well as the FK strains effects on *Striga* on maize performance in; growth attributes such as maize plant height and number of leaves and yield attributes such as stover weight, cob weight and subsequently overall grain yield within the local maize growing areas in Siaya County. Since *Striga* growth interacts with local conditions (Oswald, 2005), any approach that is intended for control of this weed must strive to combat *Striga* biologically by designing a locally efficient, affordable and available method.

Striga hermonthica (Del.) Benth is a major contributor to hunger, malnutrition and food insecurity across sub-Saharan Africa by its effects on low yields in major crops (Gressel *et al*., 2004; Schaub *et al*., 2006). This parasite attaches on to the crop hosts' roots before penetrating into the vascular system, and eventually removing water, photosynthates and minerals (Joel, 2000; Gressel *et al*., 2004; Yonli *et al*., 2005). Since crop yield is reduced when crops are infested with *Striga,* there is need for preventing the production of new *Striga* seeds and increase the crop yield in *Striga* infested land through feasible farm management solutions. Since parasitic *Striga* weed is a major biotic constraint to increased cereal production for millions of rural farm families in sub-Saharan Africa (Khan *et al*., 2008; Atera

et al., 2013), a lasting solution is urgently required to combat the menace. Despite the weed problem existing for many years, farmers knowledge on *Striga* is still limited to extension service or fellow farmers with emphasis on indigenous knowledge in Kenya (Achola, 1999). With more than 40% of farmers experiencing constraint in cereal production, knowledge on *Striga* control methods, has been restricted to hand-weeding, fallow management and manure application (Kanampiu *et al*., 2003; Okoth and Siameto, 2010). Since much of the *Striga*-infested areas have extremely high level of the weed seeds (Kanampiu *et al*., 2003). These control measures may require several seasons of repeated use before any beneficial yield is realized while some of the control measures are very expensive.

Although a number of approaches for controlling *Striga* infestations have been severally proposed (Parker and Riches, 1993; Suprapta and Khalimi, 2012), *Striga* has remained noxious and difficult to control (Ali-Olubandwa *et al.,* 2011) due to highly proliferation, high seed bank in the soil, some methods that are used to control it are environmentally unfriendly such as use of herbicides, some are also expensive such as the Imazapyr Resistant (IR) Maize. Several control measures such as cultural; uprooting and burning of *Striga* plants before flowering, field sanitation, use of *Striga* free planting materials and clean tools, crop rotation, intercropping, organic matter usage and push- pull system, host plant resistant varieties; *Striga* tolerant IR maize, herbicide application (Suprapta and Khalimi, 2012). Most of these control methods that involve resistant host-crop varieties, chemicals, crop rotation, intercropping with *Striga* host and non-host crops and soil-fertility management have been applied in Africa on various crops (Chitere and Omolo, 1993; Kanampiu *et al.,* 2003; Khan *et al.,* 2008). However, the success of most of the available approaches to control *Striga* may be limited due to its biology and socio-economic reasons (Oswald, 2005; Khan *et al.,* 2008); *Striga* has persisted in soil due to long lived *Striga* seeds in soil while the available methods have not been adopted due to limited knowledge of *Striga* lifecycle, lack of land for crop rotation (Anjichi *et al.,* 2005) and benefits that can only acrue over long repeated use, while some methods such as use of herbicides are expensive, non specific to weeds and pose environmental risks, resistant varieties are expensive and require long repeated use for any beneficial outcome while cultural methods are ineffective since crops are already damaged before *Striga* emergence. There remains exigent unanswered questions regarding the activity of local strains of *F. oxysporum* in controlling *Striga* weed in local maize and the effects of

locally isolated *Fusarium oxysporum* strains infection on *Striga* on agronomic properties of maize in Siaya County.

Limited information is currently available on the effects of *Striga* on agronomic traits in local maize; maize growth such as height and number of leaves and also yield in maize such as stover weight, cob weight and generally maize grain yield grown in Siaya County, which impedes designing appropriate control options. Furthermore, local knowledge may be relevant to the rural marginalized population but the high costs of synthetic herbicides and associated toxicity risks may discourage their integration in pest management systems (Chitere and Omolo, 1993) hence the need for use of a cheaper, environmentally friendly, locally available and weed specific *Striga* control options to curb *Striga* menace in farm fields in Siaya County. Although researchers in Africa have intensified studies on *Striga* control (Oswald, 2005; Kabambe *et al.,* 2008; Khan *et al*., 2008; Atera *et al.,* 2013), more efforts are needed to develop cost effective and environmentally friendly control options for the poor local farmers. The major threat to livelihoods of smallholder maize farmers persists in Siaya County due to *Striga* weed by impacting negatively on maize yield.

Siaya County is located in western Kenya on the shores of Lake Victoria (Kiplangat *et al.*, 2013). Agriculture and fishing are the main economic activities in this County. The area hosts several rivers, streams, and wetlands that are seldom used for irrigation. Local farming systems are characterized by a very small landholding size with very low external input use, declining soil fertility and exodus of able-bodied persons to secure jobs in urban areas (Place *et al.,* 2007). Poverty is high in areas with low rainfall and poor soil fertility. Due to erattic rainfall in Siaya County, small-scale farmers prefer '*Rachar*' the local maize landraces whose maturity is fairly guaranteed with minimal input (Anjichi *et al.,* 2005). Despite availability of several control measures for *Striga* weed such as cultural, physical, mechanical and chemical methods, the complex biology of *Striga* has limited the development of successful control methods that can be accepted and practiced by the subsistence farmers (Atera *et al.,* 2013). When searching for alternative modern technologies, adoption becomes a priority for effective attainment of perceived benefits (Kanampiu *et al.,* 2003). Biological control options such as use of locally isolated FK strains would be more effective in controlling *Striga* weed since it is weed specific, non contaminative to the environment, locally available and therefore cheap. This study focused on the use of local strains of *Fusarium* to control *Striga*

weed in local maize variety '*Rachar*' and with a view to improve growth and yield of maize in Siaya County.

1.2 Statement of The Problem

Data on response of local strains of *Fusarium oxysporum* to *Striga* infestation for local maize variety under field conditions is lacking in Siaya county. None of the available studies have been tested under field conditions. Although *S. hermonthica* is an obligate out-crossing parasite that affects a wide range of crops and environment, local strains of *F. oxysporum* obtained from infected *Striga* have not been tested in different sites and their effects on agronomic traits (growth and yield) on local maize have not been revealed.

1.3 Justification

Siaya County farms have high rates of *Striga* infestation (Atera *et al.,* 2013) hence there is need for cost-effective measures that control *Striga* weed to reduce *Striga* seed bank in soil and to maximize maize yield in the maize farm sites. Most farmers in Siaya County depend on the cropping system where high frequency of cereals is combined with limited legumes rotation and low use of fertilizer, hence an alternative approach of using local *Fusarium oxysporum* strains may alleviate *Striga* weed problem. Studies on local strains have provided promising results under green house trials, hence are expected to yield lasting solutions to *Striga* weed problems in maize fields in Siaya County and offer cropping systems that are within the reach of the resource-limited small-scale farmers in the County. The foreign isolate; *Foxy*-2 was not found to be effective in Kenya (Avedi *et al*., 2014) due to its lack of ability to control emergence and infection on *Striga*. Use of local strains of *Fusarium oxysporum* will avail non-contaminative techniques that will foster an effective maize production in *Striga* infested farm lands, which is a preriquisite for fighting poverty and hunger in Siaya County. *Fusarium oxysporum* strains attack the target weed seeds before emergence. They are therefore expected to reduce the damage to the local maize thus reducing the *Striga* seed bank in the soil and increasing the grain yield of the crop in subsequent cropping season. The use of *Fusarium oxysporum* is expected to be cost-effective with no additional labour requirement when applied as a seed treatment. *Fusarium oxysporum* strains being locally available in the soil, are cheap because they will reduce the costs, maintain the environment and will lead to better maize yields.

1.4 General Objective

To determine the efficacy of five *Fusarium* strains in controlling parasitic *Striga* weed and improve maize productivity in Siaya County.

1.4.1 Specific Objectives

1. To determine the efficacy of five pathogenic *Fusarium* strains on *Striga* infesting maize fields in Siaya County.
2. To determine the effect of *Fusarium* strain infection of *Striga* on growth and yield of maize grown in Siaya County.

1.4.2 Hypotheses

1. The local *Fusarium oxysporum* strains do not infect *Striga* parasitising/ infesting maize.
2. *Fusarium oxysporum* strains pathogenicity does not affect maize growth and yield.

CHAPTER TWO

LITERATURE REVIEW

2.1. *Striga* Botany

Striga hermonthica, is a hemiparasitic plant that belongs to the Kingdom Plantae, Order Lamiales, family Orobanchaceae. It is devastating to major crops such as rice (*Oryza sativa* L). In sub Saharan Africa, it infests, apart from sorghum and rice, also maize (*Zea mays* L), pearl millet (*Pennisetum glaucum*) and sugar cane (*Saccharum officinarum* L.).

2.1.1 *Striga* Host and Symptoms

It infects a variety of grasses and legumes in sub-Saharan Africa including rice, maize, millet, sugarcane, and cowpea. The symptoms mimic that of drought or nutrient deficiency symptoms. Wilt and stunting result from *Striga*'s ability to extract nutrients from its host. Pre-emergence symptoms are difficult to diagnose secondary to their similarity to general lack of nutrients. Once emergence of the plant has taken place, it is usually too late to mitigate damage (Atera *et al.,* 2013).

2.1.2 *Striga* Disease Cycle and Environment

Seeds of *Striga* overwinter in the soil after they are dispersed by wind, water, animal or human machinery. When the environment is correct and the seed is within a few centimeters of the host's root, it will begin to germinate. The germinating plant grows towards strigolactones released from the host root. The plant grows up the concentration gradient of these strigolactones. In the absence of strigolactones, the *Striga* will not germinate (Berner *et al.,* 1997). Strigolactones knockout plants have been used in an attempt to prevent infection by avoiding germination. Once in contact with the root, the *Striga* produces a haustorium establishing a parasitic relationship with the plant. It remains underground for several weeks while extracting nutrients. The stem while underground is round and white. After this stage, it emerges from the ground and rapidly flowers and produces seeds. The flowers self pollinate before opening. During post emergence period, the plant can perform photosynthesis to augment its metabolic demands.

2.1.3 *Striga* Evolution

The *Striga* weed has been in existence for a very long time, with some research dating back for over five decades. The rising population pressure in rural Africa, has resulted in an intensification of the traditional cropping system with consequencies of soil fertility decline and hence the *Striga* weed finds an ideal environment for its proliferation (Oswald, 2005). Despite the weed problem existing for many years, farmers knowledge on *Striga* is still limited to extension service or fellow farmers with emphasis on indigenous knowledge in Kenya (Achola, 1999). With more than 40% of farmers experiencing constraint in cereal production, knowledge on *Striga* control methods, has been restricted to hand-weeding, fallow management and manure application (Oswald, 2005; Okoth and Siameto, 2010). Since much of the *Striga*-infested areas have extremely high level of the weed seeds (Kanampiu *et al*., 2003), these control measures may require several seasons of repeated use before any beneficial yield is realized.

2.2 Effects of *Striga* on Maize Growth and Yield

Striga parasite attaches on to the crop hosts' roots (maize plant) before penetrating into the vascular system, eventually removing water, photosynthates and minerals (Joel, 2000; Gressel *et al*., 2004; Yonli *et al*., 2005). *Striga* has been shown to cause loses in crop production in cereals (Yonli *et al.*, 2005). Approximately 75% of the losses occur to the host plant before emmergence of the *Striga* weed from the soil. *Striga* affects agronomic traits/growth such as germination rates, height, number of leaves and maize yield such as stover weight, cob and grain weight (Yonli *et al.*, 2005). Yield is a quantitative trait that is functionally related to germination, height and number of leaves. Information on the effects of *Striga* on maize yield components would be useful to physiologists, modellers and plant breeders. Such information is, however, scanty on local maize grown in Siaya County. *Striga* effects ranges from extensive blotching and mild wilting, noticeable stunting to reduction in ear and tassel size, leaf wilting, rolling, severe stalk lodging, and brittleness (Gressel *at al*., 2004). In sub- Saharan Africa, yield losses in maize ranges from 8.1 to 8.5 million tons, which is equivalent to 39 to 45 percent of the total production (Gressel *at al*., 2004), hence the need to improove maize yield in Siaya County.

2.3 *Striga* Management and Control Methods

Striga weed is historically among the hardest parasitic plants to control (Kagot *et al.,* 2014). It does not have any sign of infection until emersion from the plant. It was found that *Fusarium oxysporum* may be used as a possible biocontrol of *Striga* (Zarafi *et al.,* 2015; Kagot *et al.,* 2014). *Fusarium oxysporum* is a fungus that is thought to infect the early vasculature of the *Striga* plant. It has further been demonstrated that use of nitrogen rich fertilizers reduces *Striga* infection rate (Kabambe *et al.*,2008). Although the mechanism behind this is not fully understood it is thought that the abundance of nitrogen disrupts the nitrogen reductase activity, Kim and Adetimirin (1997). This has a ripple effect resulting in the dysregulation of the plants light and dark cycle inevitably resulting in the *Striga* death.

Interest in the soil micro-flora has been on the increase in the last three decades with the aim of unravelling new bioactive compounds, particularly those active in severe environmental conditions (Damjan *et al*., 2007; Mekawey, 2010). Due to secretion of root exudates, plant roots surface (rhizoplane) and soil around the roots (rhizosphere) are the zones of intensified microbial activity. These have led to competition among the microbes such as fungi for nutrition (Thomas *et al*., 1999; Mekawey, 2010). Soil carbon depletion, nutrient stress, and light quality are driving factors for chlamydospore production in fungi. Fungi of the genus *Fusarium* easily grow in liquid cultures and the resulting suspensions can be used as a soil drench or a post-emergence spray application (Kanampiu *et al*., 2003). However, not enough time has been invested in developing control concepts or strategies for integrated weed management.

Striga weed has demonstrated a wide tolerance for soil type and temperatures and their seeds can survive in frozen soil of temperatures as low as -15°C. Since each *Striga* plant produces tens of thousands of tiny seeds that remain dormant in the soil for many years (Mourik, 2007), crop rotation as a means of *Striga* control may not be efficient in eradicating all seeds from the soil. This is because abandoning fields in search of *Striga* free land is not feasible with population pressure and also the depletion of soil nutrients (Kanampiu *et al*., 2003). Mycoherbicides such as use of *F. oxysporum* can control weeds in annual crops on a comparable or even better level than chemical herbicides which are non specific to weeds since they can be highly specific to the target weed. Since chemicals may be expensive or even pose a risk to the environment, biological control by use of *Fusarium oxysporum* aims at

bridging the gap and compensate for lack of selectivity by chemicals (Ali- Olubandwa *et al.,* 2011).

Although the weed control by use of soil borne plant pathogens have been done solely to improve growth through inoculation of seed or soil with some selected strains of *F. oxysporum* (Okoth and Siameto, 2010), risk assessment are needed to address the fate of engineered terrulic soil. *Striga hermonthica*, (Del) Benth, infests an estimated 217,000 ha in Kenya, causing annual crop loss of US $53 million (Woomer *et al.,* 2004). The life cycle of *Striga* spp. is composed of five stages: germination, haustoria initiation, penetration of host tissue, physiological compatibility and parasite growth and maturation. Biological control has been shown to be a potential alternative disease management strategy (Gauperin *et al.,* 2003; Table 2).

A number of approaches for controlling *Striga* infestations have been severally proposed (Suprapta and Khalimi, 2012), but *Striga* has remained noxious and difficult to control (Ali-Olubandwa *et al.,* 2011) due to highly proliferation, high seed bank in the soil, some methods that are used to control it are environmentally unfriendly such as use of herbicides (Kanampiu *et al.,* 2003), which is also expensive; such as the use of Imazapyr Resistant (IR) Maize. Several control measures such as cultural; uprooting and burning of *Striga* plants before flowering, field sanitation, use of *Striga* free planting materials and clean tools, crop rotation, intercropping, organic matter usage, push- pull system, host plant resistant varieties; *Striga* tolerant IR maize, herbicide application (Suprapta and Khalimi, 2012), have been used. Most of these control methods that involve resistant host-crop varieties, chemicals, crop rotation, intercropping with *Striga* host and non-host crops and soil-fertility management have been applied in Africa on various crops (Chitere and Omolo, 1993; Kanampiu *et al.,* 2003; Khan *et al.,* 2008). However, the success of most of the available approaches to control *Striga* may be limited due to its biology and socio-economic reasons (Oswald, 2005; Khan *et al.,* 2008). *Striga* has persisted in soil due to long lived *Striga* seeds in soil while the available methods have not been adopted due to limited knowledge of *Striga* lifecycle, lack of land (Anjichi *et al.,* 2005) and crop rotation; benefits that can only acrue over long repeated times, while some methods such as use of herbicides and resistant varieties are expensive, while cultural methods are ineffective since crops are already damaged before *Striga* emergence. IR Maize is resistant to *Striga* hence a better control method (Diallo *et al.,* 2007), however, its use is limited due to financial constraints to poor local farmers of Siaya County. Cultural weed

control methods such as, push and pull (Khan *et al.,* 2008), hand pulling, are ineffective because they are untimely and require long repeated use. Chemical herbicides (Kanampiu *et al.,* 2003) could also be used to control the weed but it is non specific to the target *Striga* weed, expensive and poses environmental risks, hence not acceptable to poor local farmers of the County. Biological control method (Zahran, 2008; Beed *et al.,* 2013; Zarafi *et al.,* 2015) is non contaminative, weed specific, locally available and therefore cheap and acceptable to poor local farmers of Siaya County. There remains exigent unanswered questions regarding the activity of local strains of *F. oxysporum* in controlling *Striga* weed in local maize in Siaya County.

Soil that has been contaminated by *F. oxysporum* will almost certainly remain so for a very long time (Ransom *et al.,* 1996; Dugje *et al.,* 2006; Woomer *et al.,* 2004). A total of 30 isolates of *Fusarium* have been successfully isolated from samples collected from the field where three species from rice were identified as *F. proliferatum, F. oxysporum* and *F. sacchari*. From maize, *F. subglutinans, F. proliferatum, F. verticillioides* and *F. oxysporum* were recovered from different parts of the plant and two species, *F. sacchari* and *F. verticillioides* were isolated from infected leaves of sugarcane. Fungi of genus *Fusarium* have been previously isolated from diseased *Striga* plants and have shown potential in biocontrol of the weed (Yonli *et al*., 2005; Marley *et al*., 1999). *Fusarium* species have been found to reduce the germination of *Striga hermonthica* seeds by approximately 90% in some parts of West Africa (Yonli *et al.,* 2005). *Fusarium* species have high efficacy where the fungi isolated from more than 90% of diseased *Striga* plants from Burkina Faso, Ghana, Mali and Niger had the potential of reducing germination rates under laboratory experiment in Burkina Faso (Abbasher *et al*., 1995). In West Africa, *Fusarium oxysporum* was the dominant species comprising 93% among isolates obtained from a survey on diseased *S. hermonthica* plants (Abbasher *et a*l., 1998; Berner *et al*., 1997). *F. oxysporum* that infected *S. hermonthica* included isolate *Foxy* 2 from North Ghana (Abbasher *et al*., 1995), isolate PSM197 from Samaru in Nigeria (Marley *et al*., 1999), and isolate M12-4A from Mali (Ciotola *et al*., 1995).

Limited information is currently available on the effects of *Striga* on agronomic traits in local maize; maize growth such as height and number of leaves and also yield in maize such as stover weight, cob weight and generally maize grain yield grown in Siaya County, which impedes designing appropriate control options. Furthermore, local knowledge may be relevant to the rural marginalized population but the high costs of synthetic herbicides and

associated toxicity risks may discourage their integration in pest management systems (Chitere and Omolo, 1993). Although researchers in Africa have intensified studies on *Striga* control (Oswald, 2005; Kabambe *et al.*, 2008; Khan *et al*., 2008; Atera *et al.*, 2013), studies in western Kenya revealed the two local strains of *Fusarium oxysporum* obtained from Alupe and Kibos to have mortality rates on *Striga* weed greater than 50% but was carried out under green house trials (Kagot *et al*., 2014), hence the need for maize field trials in Siaya County. In other studies, foreign isolate of *F. oxysporum* f. sp. *Strigae* (*Foxy* 2) that had been obtained from severely diseased *S. hermonthica* in North Ghana did not show substantial efficacy in controlling *Striga* weed in western Kenya (Avedi *et al.,* 2014) yet was effective in controlling *Striga* weed in Ghana, hence the need to try locally isolated *Fusarium* strains in Siaya County maize growing fields. These tremendous efforts have been supported by characterization (Kagot *et al*., 2014) and diversity among pathogenic strains of *F. oxysporum*. Data on response of local strains of *Fusarium oxysporum* to *Striga* infestation for local maize variety under field conditions is lacking in Siaya County. None of the available studies have been tested under field conditions. Although *S. hermonthica* is an obligate out-crossing parasite that affects a wide range of crops and environment, local strains of *F. oxysporum* obtained from infected *Striga* have not been tested in different sites and their effects on agronomic traits (growth and yield) on local maize have not been revealed.

2.3.1 Host Resistance/Tolerance

The advances made in the development of uniform infestation techniques allowed identification of sources of resistance to *S. hermonthica* from tropical and temperate maize inbred lines and African landrace collections (Berner *et al*., 1997; Menkir *et al*., 2012). Working with these source materials, breeders at the International Institute of Tropical Agriculture (IITA) created broad-based populations with different genetic backgrounds and improved them for resistance to *S. hermonthica* using different recurrent selection schemes. The improved populations have been sources of *S. hermonthica*–resistant maize inbred lines (Menkir *et al.,* 2012) that have been used to form hybrids evaluated in field trials in different locations across seasons. However, breeding for resistance to *S. hermonthica* in maize has been difficult because of the lack of a reliable and effective screening method, limited sources of resistance to the parasite, complex nature of the mode of inheritance, and low heritablity, (Olakojo and Olaoye, 2005). Selection and breeding programmes including

biotechnology could be the most effective approach in *Striga* weed management (Kim and Adetimirin, 1997). Although reports of genetic resistance have been made in some cereal crops such as rice in Kenya (Atera *et al*., 2013), the response of traditional varieties in *Striga*-infested areas are yet to be validated. The process of selection requires a long repeated time and high financial investment before it can acrue benefits to poor farmers of Siaya County which impedes the use of this method in the County.

2.3.2 Cultural Control

Several methods have been applied by farmers under field conditions such as hand pulling (Khan *et al*., 2008) and weeding. Although these methods have been applied by farmers, they depend on early identification of the weed and probably its often too late for controlling. Crop rotation have also been useful in reducing the weed soil seed bank. In other situation, farmers use trap crops, such as cotton, groundnut, cowpea and soyabean, which are especially beneficial in causing suicidal germination and accelerating a decline in the soil seed bank (Joel, 2000), but they need to be sown at a time when *Striga* germination is likely to be high, usually early in the rainy season, before the onset of any secondary dormancy. Catch crops are susceptible cereals which may be grown at the beginning of the season or in short rains prior to the main season, to stimulate germination of the *Striga* (Oswald, 2005; Khan *et al.,* 2008). However, they need to be destroyed before the weed can mature and set seed in which it is cumbersome and tiring. Other options such as use of dry conditions have been applied, which reduces *Striga* transpiration and its ability to draw nutrition from the host (Woomer *et al.*, 2004). However, none of the methods described above have solely provided complete control or reduce the weed soil seed bank. It is therefore essential that other alternative methods be tested to ensure complete destruction of *Striga* weed.

2.3.3 Chemical Control

This method requires good training by farmers and purchase of equipments and herbicides. Some chemical stimulants are available that will stimulate *Striga* growth in the absence of the host or any other plant, so the weed will force itself to germinate when there is no host (Kabambe *et al*., 2008). Fumigation with Methyl bromide at 350kg/ha has been shown to control *Striga* in many farms. Other chemicals such as metham and Dazomet have been used to control the weed (Achola, 1999). However, financial constraints may impede or hinder

adoption of this method by poor local farmers. Herbicide resistant maize have been used to control *Striga* in Eastern and Central Africa but with little success (Diallo *et al.,* 2007). Chemical herbicides (Kanampiu *et al.,* 2003) are non specific to the target *Striga* weed, expensive and poses environmental risks, hence not adopted by poor local farmers of Siaya County.

2.3.4 Biological Control

The constraints posed by all available control methods where several setbacks can only be overcome by integrated approaches (Oswald, 2005; Okoth & Siameto, 2010). For instance, it is considered that under certain circumstances, biological control of the water hyacinth weed alone will not be sufficient to effectively reduce the weed stand in a relatively short period of time (Bennet and Zwolfer, 1968; Cordo, 1996). Therefore, an integrated approach for the control of the weed is recommended which may consist of mechanical and/or systematic manual removal, and the use of herbicides in particular infested sites (Okoth and Siameto, 2010). The mite *Orthogalumna terebrantis*, although not intentionally introduced into the US, also proved to be specific enough to be used in other countries. Thus, these four agents are currently in use in many countries in the tropical and sub-tropical regions of the world in which water hyacinth was introduced.

In South America, where water hyacinth originated, about 17 species of arthropods have been identified, each of which provides different scope for biological control. Four of these species are in use worldwide (*Neochetina eichhorniae, N. bruchi*, *Niphograpta* and *Orthogalumna*), six have received renewed interest (*Eccritotarsus*, *Xubida*, *Cornops*, *Paracles* and *Thrypticus*), and seven are poorly known. Two species from the second group, *Eccritotarsus* in South Africa and *Xubida* in Australia, have recently been liberated, and others are being investigated in South Africa (PPRI) and Argentina (USDA). Recent explorations in Argentina revealed that the petiole-mining fly *Thrypticus* sp., once thought to be a single species, is actually a complex of species highly specialized on the water hyacinth family. Similar to water hyacinth weed, *Striga* weed poses a challenge when trying to determine appropriate method due to economic and environmental constraints. Therefore, practical advice have been recommended on where and how to use short-term control methods to complement the effect of biological control (Achmad *et al.,* 1971). There is need for an integrated control

since one method of biological control is not sufficient enough to eradicate the menace caused by the *Striga* weed (Bennet *et al*., 1968; Cordo, 1996). The increasing worldwide problem caused by *Striga* weed necessitates both short- and long-term control or the integration of several techniques in which biological control is an essential component. Experience gained in biological control of water hyacinth in different regions provides useful information that can be adopted in the control of *Striga* by use of different strains of *Fusarium oxysporum* f.sp. *Strigae* from different locations.

More interest have been intensified on the use of natural enemies of *Striga* weed parasites such as *Celosia argentia* (*Striga* chaser) as a biological control of the parasitic *Striga* weed (Olupot *et al.,* 2003) and use of pathogens to prevent their growth and spreading. Soil pathogens as mycoherbicides, especially *Fusarium spp*., e.g *Fusarium oxysporum* (Ciotola *et al.,* 1995), have been applied in several researches. Biological control of *S. hermonthica* by soil application of a mycoherbicide containing *Fusarium oxysporum* is weed-specific, has low environmental impact and cost-effective (Ali-Olubandwa *et al.,* 2011), therefore *Fusarium oxysporum* attacks the target weed before emergence and hence reduces the damage to the host crop, reduces the *Striga* seed bank in the soil, prevents production of new seeds and increases the grain yield of the crop in the same cropping season (Zarafi *et al.,* 2015).

Table 1: Researches on *Striga* Biocontrol Methods in Sub-Saharan Africa.

Location	Crop	Control method	Findings	Source
Ghana	Maize and sorghum cultivars	*Fusarium oxysporum* Schlecht. (*Foxy* 2 and PSM197)	significant reduction in *Striga* emergence and flowering	Schaub *et al*., 2006
Mali	Sorghum	(Inoculum) *Fusarium oxysporum* isolate *M12-4A*	Reduced *S. hermonthica* emergence by 92%.	Ciotola *et al*., 1995
Uganda	Sorghum	Interplanting crop with *Celosia argentia* (*Striga* chaser)	*Striga* seed germination was suppressed	Olupot *et al*., 2003
Kenya	Maize	allelopathic tactics	Development of haustoria of *S. hermonthica* the parasite was	Khan *et al*., 2008

			suppressed	
Kenya	Maize and Beans	Soil amendments	Reduced root infection and Mavuno fertilizer suppressed root colonisation by *Fusarium* spp.	Okoth and Siameto, 2010
Burkina Faso	Sorghum	Biocontrol by use of 15 isolates of *Fusarium oxysporum*	Fungus reduced *Striga* emergence by 50%	Yonli *et al*., 2005

Research has shown that the population of the host has been regulated by the biological control agent. Several reports have been made in parts of East Africa (Achola 1999; Ali-Olubandwa *et al.,* 2011), such as *Foxy* 2 efficacy in Ghana but ineffective in western Kenya (Avedi *et al.,* 2014) and two local strains from Alupe and Kibos (Kagot *et al.,* 2014) that were found to be effective in controlling *Striga* but only under green house trials.

More interest has been intensified in the use of natural enemies of *Striga* weed such as parasites of pathogens to prevent their growth and spreading. Soil pathogens as mycoherbicides, especially *Fusarium spp*., e.g *Fusarium oxysporum* (Ciotola *et al*., 1995), have been applied in several researches (Schaub *et al*., 2006; Yonli *et al*., 2005). In this case, the population of the host has been shown to regulate the population of the biological control agent. Several reports are available in parts of East Africa (Ali-Olubandwa *et al*., 2011), however, further work is still needed under different farm sites before conclusions are made on reliability of *Fusarium oxysporum* in controlling the *Striga* weed and its effects on agronomic properties of maize in Siaya County.

2.4 *Fusarium oxysporum*

2.4.1 Biology of *Fusarium oxysporum*

Fusarium oxysporum produces three types of morphological features, asexual spores: microconidia, macroconidia, and chlamydospores (Agrios, 1988). Microconidia are one or two celled, and are the type of spore most abundantly and frequently produced by the fungus under all conditions. It is also the type of spore most frequently produced within the vessels of infected plants. Macroconidia are three to five celled, gradually pointed and curved toward the ends. These spores are commonly found on the surface of plants killed by this pathogen as well as in sporodochia like groups. Chlamydospores are round, thick-walled spores,

produced either terminally or intercalary on older mycelium or in macroconidia. These spores are either one or two celled (Agrios, 1988). In solid media culture, such as potato dextrose agar (PDA), the different special forms of *F. oxysporum* can have varying appearances. In general, the aerial mycelium first appears white, and then may change to a variety of colors - ranging from violet to dark purple - according to the strain (or special form) of *F. oxysporum.* If sporodochia are abundant, the culture may appear cream or orange in color (Smith *et al*., 1993).

2.4.2 *Fusarium oxysporum* Strains

Pathogenic strains of *F. oxysporum* strains have received much attention due to their effects on economically important crops (Alves-Santos *et al*., 1999). Most of these strains are saprophytic and can survive for many years in the soil. It has been observed that pathogenic strains are host specific and hence classified into numerous *formae speciales* and races (Edel *et al*., 1995). Previous studies on the strains belonging to pathogenic vegetative compatibility groups where polymorphisms were examined in the intergenic spacer region found strains belonging to *F. oxysporum f. sp. phaseoli* to be a monophyletic group within *F. oxysporum* (Alves-Santos *et al*., 1999). While studying vegetative compatibility. Biocontrol potential of antagonistic *Fusarium* spp. can be enhanced by manipulating existing wild-type strains using conventional mutagenesis. This was carried out by Ghini *et al.* (2000) while stuying the effects on soil microbial biomass and activity by two *F. oxysporum* strains (Strain T26/6 and strain 233/1 C5).

Although molecular tools have been applied to characterize the diversity among pathogenic strains of *F. oxysporum* strains (Armstrong and Armstrong, 1981; Edel *et al*., 1995), few studies are available on the effects of different strains on *Striga* weed in maize growing areas. For instance, while carying out studies in western Kenya, Kagot *et al*. (2014) found *Fusarium oxysporium* strains to be the most frequent fungal species isolated from diseased *S. hermonthica* collected from Kibos and Alupe followed by *F. chlamydosporium* and *F. equiseti*. In their green house trials where maize was grown in 5- litre plastic pots, they found that two strains of *Fusarium oxysporum* had weed mortality rates greater than 50%, one having 60% and the other having 58%. However, no field trials are available for these strains isolated from diseased *Striga* in Siaya County maize farm fields and their effects on *Striga*

and their responsiveness to maize growth and yield since Siaya County has high prevalence of *Striga* in maize fields (Atera *et al.,* 2013).

Different strains of *F. oxysporum* f.sp. *Strigae* have been isolated from diseased *Striga* plants. These include; isolate M12-4A strain from Mali which controlled *Striga* emmergence by 92% (Ciotola *et al.,* 1995); *Foxy 2* from Ghana (Abbasher *et al.,* 1995) and PSM 197 strain which was isolated from Samaru, Nigeria (Marley *et al.,* 1999), both had significant reduction on *Striga* emmergence and flowering (Schaub *et al.,* 2006) but *Foxy 2* was ineffective in controlling *Striga* emmergence in Kenya (Avedi *et al.,* 2014); strains T26/6 and 233/1 C5 (Ghini *et al.,* 2000) were potential biocontrols against *Striga*.

2.4.3 *Fusarium oxysporum* Host

Fusarium oxysporum is very virulent and has a wide range of potential plant hosts (Amadi *et al*., 2012; Zarafi *et al.,* 2015). As a plant pathogen, it infects a wide variety of hosts, such as tomato, cotton, banana, maize and even flowers (Amadi *et al*., 2012; Polizzi *et al*., 2010). *Fusarium oxysporum* could be split into a number of *formae speciales* (f.sp.) based on hosts and symptoms. The *formae speciales* infect a variety of plant hosts at different stages of growth from germination to flowering (Amadi *et al*., 2012). For instance, these includes: *Fusarium oxysporum f.sp*. *asparagi* (fusarium yellows on asparagus); *f.sp*. *callistephi* (wilt on China aster); *f.sp*. *cubense* (Panama disease/wilt on banana); *f.sp*. *dianthi* (wilt on carnation); *f.sp*. koae (on koa); *f.sp*. *lycopersici* (wilt on tomato); *f.sp*. *melonis* (fusarium wilt on muskmelon); *f.sp*. *niveum* (fusarium wilt on watermelon); *f.sp*. *pisi* (on edible-podded pea); *f.sp*. *tracheiphilum* (wilt on Glycine max); and *f.sp*. *zingiberi* (fusarium yellows on ginger) (Conway and Machardy, 1978) and *f.sp. strigae* (fusarium wilt on maize).

2.4.4 *Fusarium oxysporum* Distribution

Although the distribution of *F*. *oxysporum* is known to be cosmopolitan, the different *formae speciales* (f.sp.) of *F. oxysporum* often have varying degrees of distribution (Jumjunidang and Soemargono, 2012). *Fusarium oxysporum* possesses biological characters that are both very specific and varies in their different virulence between and within races and strains as well as the persistent ability in the baring soil up to 40 years (Jumjunidang and Soemargono, 2012). Due to these unique characteristics, several methods have been used to study the diversity, genotypes, ecology and population of the pathogenic fungi and includes; vegetative

compatibility group test, volatile aldehydes production, electrophoresis karyotyping, AFLP analysis among others (Jumjunidang and Soemargono, 2012).

2.4.5 Symptoms of *Fusarium oxysporum*

Fusarium oxysporum and its various *formae speciales* have been characterized as causing the following symptoms: vascular wilt, yellows, corn rot, root rot, and damping-off (Polizzi *et al.*, 2010). The most important of these is vascular wilt. Among the vascular wilt-causing *Fusaria*, *Fusarium oxysporum* is the most important species. Strains that are rather poorly specialized may induce yellows, rot, and damping-off, rather than the more severe vascular wilt. In general, fusarium wilts (Polizzi *et al.,* 2010) first appear as slight vein clearing on the outer portion of the younger leaves, followed by epinasty (downward drooping) of the older leaves. At the seedling stage, plants infected by *F. oxysporum* may wilt and die soon after symptoms appear. In older plants, vein clearing and leaf epinasty are often followed by stunting, yellowing of the lower leaves, formation of adventitious roots, wilting of leaves and young stems, defoliation, marginal necrosis of remaining leaves, and finally death of the entire plant. Browning of the vascular tissue is strong evidence of fusarium wilt. Further, on older plants, symptoms generally become more apparent during the period between blossoming and fruit maturation.

2.4.6 Pathogenicity of *Fusarium* on *Striga*

F. oxysporum is an abundant and active saprophyte in soil and organic matter, with some specific forms that are plant pathogenic (Yonli *et al.,* 2005). Its saprophytic ability enables it to survive in the soil between crop cycles in infected plant debris. The fungus can survive either as mycelium, or as any of its three different spore types (Marley *et al*., 1999). Healthy *Striga* plants can become infected by *F. oxysporum* if the soil in which they are growing is contaminated with the fungus. The fungus can invade a *Striga* plant either with its sporangial germ tube or with mycelium by invading the plant's roots (Yonli *et al*., 2005). The roots can be infected directly through the root tips, through wounds in the roots, or at the formation point of lateral roots (Marley *et al*., 1999). Once inside the *Striga* plant, the mycelium grows through the root cortex intercellular. When the mycelium reaches the xylem, it invades the vessels through the xylem's pits. At this point, the mycelium remains in the vessels, where it usually advances upwards toward the stem and crown of the plant. As it grows the mycelium

branches and produces microconidia, which are carried upward within the vessel by way of the plants sap stream. When the microconidia germinate, the mycelium can penetrate the upper wall of the xylem vessel, enabling more microconidia to be produced in the next vessel. The fungus can also advance laterally as the mycelium penetrates the adjacent xylem vessels through the xylem pits (Joel, 2000; Gressel *et al.,* 2004 Yonli *et al.,* 2005).

Due to the growth of the fungus within the *Striga* plant's vascular tissue, the plant's water supply is greatly affected. This lack of water induces the leaves stomata to close, the leaves wilt, and the plant eventually dies. It is at this point that the fungus invades the plant's parenchymatous tissue, until it finally reaches the surface of the dead tissue, where it sporulates abundantly (Gressel *et al.,* 2004; Yonli *et al.,* 2005). The resulting spores can then be used as new inoculums for further spread of the fungus.

2.4.7 Epidemiology and Management of *Fusarium oxysporum*

F. oxysporum is primarily spread over short distances by irrigation water and contaminated farm equipment. The fungus can also be spread over long distances either in infected transplants or in soil. Although the fungus can sometimes infect the fruit and contaminate its seed, spreading of the fungus by way of the seed is very rare (Agrios, 1988). It is also possible that the spores are spread by wind. Since *F. oxysporum* and its many special forms affect a wide variety of hosts, some effective means of controlling *F. oxysporum* include: disinfestations of the soil and planting material with fungicidal chemicals (Kanampiu *et al.,* 2003), crop rotation with non-hosts of the fungus, or by using resistant cultivars (Kanampiu *et al.,* 2003; Menkir *et al.,* 2012).

There is growing interest in using *Fusarium* strains as a form of biological control. Certain pathogenic strains of *F. oxysporum* could be released to infect and control invasive *Striga* weed species. Disease-suppressive soils and antagonistic microorganisms have been reported to have a potential to suppress fusarium wilt efficiently (Ciotola *et al.,* 1995; Mandeel *et al.,* 1999). However, the success of biological control depends on many biotic and abiotic factors, e.g. the plant-microbial interactions factors. In addition, *F. oxysporum* may compete with other soil fungi that act as pathogens of important crops. It is with this background that this study was conducted to determine the level and extent of infestation of maize fields with *Striga* during the growing seasons; long and short rain seasons in Siaya County, Kenya and to

determine the level of pathogenicity of *F. oxysporum* strains on *Striga* and its efficacy on growth and yield of maize in the County.

2.4.8 Integrated Approach

Although numerous approaches have been applied in control of *Striga* weed as described (see literature, Table 2), none of the treatments has been proven to achieve complete elimination of *Striga*. While some approaches may proove more effective in controlling the *Striga* weed over others (Kabambe *et al*., 2008), integration of two or more methods may be essential for any substantial reduction of *Striga* problems in maize growing regions (Khan *et al*., 2008). Furthermore, such integrated treatments will almost certainly need to be repeated over a number of years for long-term control. A range of programmes have been proposed depending on the initial density of *Striga* (Parker and Riches, 1993), which involves a combination of rotation, varietal selection, soil fertility enhancement and mixed cropping, supplemented in all cases by hand-pulling (Khan *et al*., 2008), herbicide application, all of which are aimed at reducing *Striga* seedbank within the soil. If local strains of *Fusarium* could be established to be effective, then it would be cheaper to use and environmentally friendly thus easily integrated with the other *Striga* control technologies to reduce the harmful effect of *Striga* and improve maize productivity.

2.5 Maize (*Zea mays* L.)

The origin of maize (*Zea mays* L.) in Kenya provides insights into the varieties cultivated in most regions. Maize originated in America through Europe in 1494 and later on introduced to Africa during the 16th century. Maize (*Zea mays* L.) is the most important cereal in Kenya and is the staple food for over 90% of the population (Odhiambo and Ransom, 1996). Maize is known to evolve with tolerance to low input supply and drought tolerance (Odhiambo and Ransom, 1996; Anjichi *et al.*, 2005). Few farmers in Siaya County grow improved varieties which involve higher transaction costs in procuring seeds (Melinda and Olwande, 2011). Given that rainfall in Siaya County is erratic, many small-scale farmers prefer '*Rachar*' the local maize landrace whose maturity is fairly guaranteed with minimal rainfall. This is a white kernel, white/red cobbed small sized maize type that was used in this study.

2.6 Maize Production and Consumption in Kenya

In Kenya, approximately 1.6 million ha are under maize production each year. Out of these, 80% is owned by smallholder farmers (Kibaara *et al*., 2008). In the moist mid-altitude zone of western Kenya, which is drought prone, maize is an important crop grown by almost all households in at least one cropping season per year (Odhiambo and Ransom, 1996; Kibaara *et al.,* 2008). With the recognition that technology has the potential to improve the livelihoods of smallholder farmers and rural families through increased agricultural productivity and improved environmental sustainability (Khan *et al*., 2008), most immediate gains in poor households' welfare may be achieved through agriculture. While the linkage with agriculture is especially strong for the first millenium development goal-MDG (eradicating poverty and hunger), all MDGs had direct or indirect linkages with agriculture (World Bank, 2000). According to the ministry of Agriculture, estimates between 2000 and 2008 showed that Nyanza region was the third largest maize contributor to the national production after Rift Valley and Western regions. The records show that 26 million bags were produced nationally in 2008 and the consumption rate stood at 35 million. This presented a deficit of 9 million bags. Out of the total, Nyanza region contributed about 2 m bags (Melinda and Olwande, 2011). With the Kenya's population estimated at approximately 39 million people (2010 census), the monthly maize requirement of 3.5 million bags can not be satisfied by Nyanza's annual production. Upward trend in the cost of inputs, drought and the rising levels of *Striga* weed in some regions such as western Kenya could have contributed to the downward trend in productivity of maize in 2008 and 2009 (Appendix 5; National annual maize production in 90 Kg Bags. Source: Ministry of Agriculture (MoA) 2012.

Table 2: Maize Production Trends in Bondo Sub- County and Siaya County

Table 2a: Maize Area, Production and Yield Trends in Siaya County

Year	Area (in ha)	bags	bags/ha
1999	30.329	422.217	14
2000	34.134	512.010	15
2001	34.135	454.448	13
2002	34.548	482.290	12
2003	38.980	515.815	16
2004	33.255	338.586	10
2005	34.041	342.894	12
2006	28.244	480.148	17
2007	31.892	478.380	15
2008	30.433	365.200	12

Sources: Farm Management Hand book of Kenya, Vol. II. (2009)

Table 2b: Maize Area, Production and Yield Trends in Bondo Sub- County

Year	Area (ha)	Production (metric tons)	Yield (tons/ha)
1998	14.661	11.186	0.8
1999	8.965	9.682	1.1
2000	8.808	4.356	0.5
2001	8.259	8.997	1.1
2002	10.449	12.225	1.2
2003	9.469	11.930	1.2
2004	10.425	6.568	0.6
2005	12.640	13.622	1.1
2006	13.375	18.056	1.3
2007	14.000	19.235	1.4
2008 reduced Bondo	7.700	7.277	0.9

Sources: Farm Management Hand book of Kenya, Vol. II. (2009)

According to the Farm Management Hand book of Kenya (2009), data from Bondo sub County indicates that maize yields averaged at 1.4 tons per ha and dramatic drops in some years (Table 2b). The low yield of maize was attributed to drought but dramatically dropped due to inadequate soil fertility. This contributed to food insecurity; for example, in 2008,

130,030 bags were produced against the required amount of 217,170 bags of cereals. There are many projects but no focus on soil fertility.

In Siaya County (Table 2a), maize is not only the most important food crop but is becoming a reliable source of cash too because demand and price increase considerably in the long run. The deficit in cereal production was about 20% in 2000 and 40% in 2009. Due to land shortage, the hectarage of maize does not increase any more. The low yields are attributed among others: High levels of *Striga* weed infestation, poor weed management, low use of appropriate seeds with insufficient selection of the different lengths of growing periods and low inputs of fertilizers. With increased fertilizer prices, higher inputs will only pay if the other points are solved.

Increased productivity in maize and efficient markets in sub- Saharan Africa in conjunction with rational government policies can dramatically alter the economic contribution of the maize subsector. With proper reforms in place, the maize industry will become a key element in accelerating growth and reducing poverty. Ali-Olubandwa *et al*. (2011) found that use of uncertified seed by farmers, late farm operations, lack of finance and lack of fertiliser as the main factors that hindered maize production in Western Kenya during the agricultural reform era. Although increased pest pressure on maize has been reported especially for stem borer (De Groote, 2002), there are no systematic physical measurements indicators of losses attributed to *Striga* weed in western Kenya.

2.7 Constraints to Maize Production

Many challenges impede on-farm maize yield leading to serious food shortages and malnutrition. The constraints to maize productivity ranges from poverty, inadequate technical on-farm knowledge, low soil fertility, low soil pH and *Striga* weed infestation (Avedi *et al*., 2014). *Striga* weed is the dominant parasitic weed in Western Kenya (Khan *et al*., 2008; Avedi *et al*., 2014), being the major threat to maize production, with losses as high as 70% (Khan *et al*., 2008). The *Striga* weed infestation can be accelerated under low soil fertility and drought conditions (Atera *et al*., 2013). Four species of the parasite cause economic losses in cereal crops and these are *S. hermonthica* (Del.) Benth., *S. asiatica* (L.) Kuntze, *S. aspera* (Willd.) Benth. and *S. forbesii* Benth. Among these, *S. hermonthica* is the most widespread and causes the greatest losses in Siaya County (Atera *et al*., 2013; Avedi *et al*., 2014). Maize is the dominant cereal crop in sub-Saharan Africa where the *S. hermonthica*

problem has been most severe (Atera *et al*., 2013*). S. hermonthica* has been rapidly spreading mainly due to anthropogenic activities, which contaminates agricultural land (Khan *et al*., 2008; Avedi *et al*., 2014), with farming practices such as monocropping aggrevating the situation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Sites

This study was carried out at three farmers' sites with history of *Striga* infestation in Siaya County. The driest month is January with 17 mm rainfall. Most precipitation falls in October, with an average of 146 mm with lowest average temperature for the year at 20.8°C. The warmest month of the year is February with an average temperature of 25.3°C (Appendix 2). Siaya County has a population density of approximately 300 people km^{-2}. The County borders Busia County to the North, Kakamega County to the Northeast, Vihiga County to the East, Kisumu to the South East, with Lake Victoria to the South and West. The County is inhabited by nine communities namely: Yimbo, Alego, Uyoma, Gem, Ugenya, Sakwa, Usonga, Asembo and Uholo.

Siaya town, the headquarters of the County is an economic hub with massive potential for providing for the country's needs. Agriculture and fishing are the main economic activities. Local farming systems are characterized by very small landholding size with very low external input use, declining soil fertility, and exodus of able-bodied persons to secure jobs in urban areas (Place *et al.,* 2007). Poverty is high in areas with low rainfall and poor soil fertility. The area hosts several rivers, streams, and wetlands that are seldom used for irrigation. The mean annual rainfall of approximately 1200-1600 mm with a bimodal distribution pattern between April – June (Long rains) and September – November (short rains). January - March are usually the driest and hottest months by Kiplangat *et al.*,(2013).

3.1.1 Bar Olengo Site

Bar Olengo site (0°1'0" N and 34°12'0" E), has warm, dry and humid climate. The average annual temperature in Bar Olengo site is 24°C and average annual rainfall is 1035 mm on a bi-modal rainfall pattern of long rains occurring between March and May and short rains occurring between October and November (Appendix 2; MoA, County Government of Siaya).

3.1.2 Bondo Site

Bondo site, 0°14'19" N and 34°16'10" E has warm, dry and humid climate with mean annual rainfall ranging between 800-1600 mm on bi-modal rainfall pattern of long rains occurring between March and May and short rains occurring between October and November. Temperatures too vary with mean of 22.5ºC and evaporation varies between 2000 mm and 2200 mm annually. (Appendix 2; MoA, County Government of Siaya).

3.1.3 Sagam Site

Sagam site, (0°33'36" N and 34°17'10" E). The rainfall amounts range between 1,500 and 1,900 mm per annum, the altitude ranges between 1,250 and 1,600 m above sea level while the mean temperature is 21°C. (Appendix 2; MoA, County Government of Siaya).

3.2 Experimental Design

The experimental design was a complete randomised block design with 3 replications in each site. Each site measured 28 × 25 m. A total of 18 plots per site measuring 5.5 × 3.75 m were arranged in 3 blocks, with each block consisting of 6 plots. The 3 blocks were arranged horinzontally at 5.5 m each and separated from each other by 0.75m strip (Appendix 1). Horizontal distance was set at approximately 28m, having 6 plots of 3.75m each separated from each other by a 1m path. Each plot had 9 rows, where each row had 8 plants, constituting a total of 72 maize plants per plot. Each treatment plot had maize seeds planted with *Fusarium* strains. A parallel control was maintained in each site during the growing period where seeds were planted without *Fusarium* strain inoculant. The experiment was carried out during the long rains and short rains of 2013. The layout is shown in Appendix 1. At each site, a trench 0.5 m wide and 1 m deep was dag to prevent interference on the experiment from the surrounding environment through agents such as run-off and soil colonization. A barbed wire fence surrounded the field, and a steel gate was installed to restrict access into each site. A footbath containing disinfectant (HighChem East Africa Ltd, Nairobi, Kenya) was placed at the entrance to decontaminate any person upon entry and exit from the sites. The *Fusarium oxysporum f. sp. Strigae* strains (Table 3) from five different sites were used to inoculate maize seeds before planting.

3.3 Fungal Strains

3.3.1 Collection and Isolation of Fungal Strains Infecting *Striga hermonthica*

Samples of diseased *S. hermonthica* plants showing signs of necrosis and wilting were uprooted from farms in Kosele in Rachuonyo sub County, KALRO CYMMIT-Kibos, Siaya Agricultural Training Centre (ATC) and farms in Bondo sub-county during June 2012. They were placed in paper bags before transportation to the Maseno University laboratory. The *Striga* plant samples were cut into small pieces of 1.5 cm length and placed in a suitable sterilizing solution (1% sodium hypochlorite, NaOCl) for 5 minutes. The tissues were removed from sterilizing solution then rinsed thoroughly (3 times) with distilled water. Half strength potato dextrose agar (PDA) was prepared and ammended with Chloromphenicol antibiotic then incubated at 25°C for 24 hours and observed to check out for a purplish mycelia establishment. Series of dilutions were prepared in sterile water using a plug of the grown characteristic fungal mycelia. Observations were made using compound microscope to guide the plating dilutions and plating out of 0.1 ml for establishment of pure colonies from several dilutions and plate on ½ PDA sterile media. Ten dilutions were made and fewer colonies established were pure cultures thus easy isolation. Repeat plating for pure cultures were carried out ten times till a clean culture (purplish) was obtained. Morphological identifications of the *Fusarium* strains were made using the criteria of Leslie and Summerell (2006). The aerial mycelium appeared white, then changed to purple. This was used for morphological identification of the *Fusarium* fungi.

3.3.2 Strains of the Isolated Fungi

The *Fusarium oxysporum* strains used are shown below (Table 3) and phylogenic tree, (Appendix 4).

Table 3: *Fusarium oxysporum* f.sp. *Strigae* Strains Sources

Treatment	Source
FK1	Kosele Centre
FK2	Kosele Farm
FK3	Siaya ATC
FK4	Bondo
FK5	KALRO CIMMYT-Kibos
Control (C)	Uninoculated maize

3.4 Land Preparation

The land was prepared in the long rain season using an ox-drawn plough before the rains. Harrowing followed immediately with the on-set of rains and finalized with a fine plough before planting. In the short rain season, land was prepared manually by hand using hoes and planting carried out in the third week of the season. All the three sites; Bar Olengo, Bondo and Sagam were prepared in a similar manner.

3.5 Maize Seed Dressing

Local seed "Rachar" was used in all the study sites. All seeds were primed for 10 hours and dressed at the rate of 40g of *Fusarium oxysporum* per 600 seeds at Maseno University microbiology laboratory based on Woomer *et al.* (2004). The control was dried without any dressing. All the seeds were placed under shade to dry for both long rain and short rain seasons for five hours.

3.6 Field Management

3.6.1 Artificial Field Inoculation

S. hermonthica seeds were obtained from the KARI-CIMMYT collaborative facilities at Kibos. These seeds had been collected from maize fields in Siaya County that were heavily infested by *S. hermonthica*. The seeds were already mixed with sand as described by Berner *et al*. (1997). One table spoonful of *S. hermonthica* seed-sand mixture of approximately 100 *S. hermonthica* seeds was placed in every planting hole.

3.6.2 Maize Management

Seeds of maize were sown in ridges with a spacing of 70cm between rows and 30cm within rows in each site. Two maize seeds were planted in each hole. The rows were arranged horizontally in the layout as shown in appendix 1. There were a total of 9 rows having 8 plants in a row, making a plant population of 72 per plot. Fertilizer (DAP granules) was applied at the rate of 46 kg P_2O_5 and 60 kg N per hectare. Two weeks after germination, the maize seedlings were thinned to one plant per hole. Hand weeding was done by uprooting individual weeds after two weeks for all weeds except *S. hermonthica*. The weeds were removed thereafter continually by hand-pulling to avoid interactions with *Striga* development.

3.7 Data Collection

3.7.1 Edaphic Characteristics

Three replicate soil samples were collected from each block at each site using a soil corer to a depth of 30 cm. The samples were air dried in the greenhouse for two weeks and passed through a 2 mm sieve and subjected to laboratory analysis. Soil pH was determined by putting freshly ground 50 g homogenized soil into plastic bottles with 100 ml of distilled water and stirred for 1 hour. A calibrated pH meter was used for pH determination. The other portions were bagged and carefully labelled for nitrogen, carbon and phosphorus analysis. A fraction from each site was homogenized in a ball mill where 100 mg of soil was analysed to determine their N (%) by means of elemental analysis, particle size, soil available P (mg/100g), C (%) and Cation Exchange Capacity (meq/100g). These results were then replicated. All laboratory analysis followed the methods described by Okalebo *et al.* (2005).

3.7.2 Maize Plants Sampling Procedure

Within each plot, rows 1 and 2 and rows 8 and 9 were regarded as guard rows and maize plants at the end of rows as guard plants hence they were excluded from the samples. The samples comprised of 4 alternate tagged maize plants from each of the 5 rows. This translated to 20 plants per plot. Tagging of maize plants was done using a visible red tag at each stem of sampled maize plants from week 3 after germination. In the event that any of the tagged plants was destroyed due to any cause, the preceeding maize plant was tagged and this was noted, with the reason of retagging given. The tags were maintained in a visible way hence addition of new red tags every 4 weeks.

3.7.3 Maize Performance

Agronomic parameters of maize; plant height, number of leaves, stover weight, cob weight and grain yield during the growing seasons were recorded. Plant height; was measured using a ruler (cm) from stem base to youngest leaf apex on tagged maize plant in each plot. This was done and recorded every 7 days from week 4 to week 10. Means were calculated from the replications to obtain mean maize height per plot per FK strain treatments and control plots were recorded. 20 maize plants were tagged in each plot and monitored during each growing season.

Number of leaves were also counted. This was done and recorded every 7 days from week 4 to week 10.

Maize yield attributes such as stover weight, cob weight and generally grain yield were determined at the 14^{th} week (physiological maturity of maize) during harvesting. Means were calculated from the replications to obtain mean stover weight, cob weight and grain yield per plot.

3.7.4 *Striga* Emergence and Infection Rates

The number of emerged *Striga hermonthica*, infected *Striga* and wilt symptoms were assessed. The total number of emmerged *S. hermonthica* plants within each plot was determined by counting within 15cm radius of each tagged maize stem and recorded every 7 days from week 4 upto week 10. The total number of *Striga* plants that had emerged were

calculated at the 10th week. Means were calculated from replications to obtain mean *Striga* emergence per plot.

Striga infection was then determined by counting the number of infected *Striga* plants as a proportion of the total number of *Striga* plants in each plot which was used to calculate percent infection. Any *Striga* plant that showed signs of infection was counted and recorded as infected *Striga* by Olakojo and Olaoye (2005*)*, this was determined during the counting of emerged *Striga* plants every 7 days; from the 4th to 10th week.

3.7.5 Yield Parameters

At physiological maturity (week 14), the number of maize cobs on the sampled plants per plot were counted. The total weight (g) of maize cobs and stover weight (g) per plot were measured using a portable electronic scale (Constant 14192-7, South Korea). Obtained data for each parameter of cob weight and stover weight were used to calculate means for replicates. Grain moisture content was determined by randomly picking 3 cobs per plot, then extracting a grain from each cob, and placing the three in a grain moisture meter (GMK-303A, G-won Hitech Co., Ltd, Seoul, South Korea). This was done three times to get an average moisture content. The weight of the cobs per plot and the moisture content (MC) were used to determine yields in tones per hectare using the formula described by De Groote *et al*., (2002) as shown below:

$$Yield(tonha^{-1}) = \frac{FW(100 - MC_1) \times S \times 10000m^2}{(100 - MC_2) \times Pm^2 \times 1000Kg}$$

Where:

FW was weight of harvested cobs (Kg); MC_1 was the moisture content (%) in grains at harvest and MC_2 was the required moisture in maize grain at storage (i.e. 13%); S was the shelling percentage (85%); P = plot size.

3.8 Data Analysis

All data for *Striga* emergence, *Striga* infection rates by *Fusarium* strains (FK strains), maize height, number of leaves, stover weight, cob weight and grain weight were subjected to analysis of variance (ANOVA) with means of individual per plot combined across the seasons and sites using Statistical Analysis system (SAS) software, version 9.1 software.

Significant differences among the means were separated using Fisher's least significant difference (LSD) at 5% level of probability.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil Properties in Siaya County

Bar Olengo had ferralsols, which are common soils in South Nyang'oma and Usigu divisions. Bondo site had poor shallow soils of sandy loams and Acrisols while Sagam site had valley swampy black soil, which was classified as clayey black cotton soil. This soil was very rich in nutrients and had been previously used for cultivating vegetables and arrow roots. The three sites recorded a pH of 4.0, 4.1 and 6.4 for Bar Olengo, Bondo and Sagam respectively. The pH values for Bar Olengo and Bondo sites were way below the required minimum (5.5) for maize growth and development (Woomer *et al.,* 2004). Generally, Sagam site recorded higher soil nutrients compared to Bar Olengo and Bondo. Total N, 0.17%, 0.15% and 0.35% were recored at Bar Olengo, Bondo and Sagam sites, respectively. Organic carbon was also low at Bar Olengo; 1.12%, lowest in Bondo at 0.83% and high at Sagam, 1.49%. Phosphorus was 23.4mg/100g at Bar Olengo, 17.6mg/100g in Bondo and 13.4mg/100g at Sagam (Appendix 3).

The soil pH of Sagam site, was 6.4 which was above the required minimum (pH above 5.5) for maize growth and hence Sagam site had better FK strains pathogenicity (Table 4 and 5) in controlling *Striga* weeds unlike Bar Olengo and Bondo soils which were highly acidic decreasing the pathogenicity of FK strains on *Striga* (Appendix 3). Low soil pH leads to low soil fertility (Woomer *et al.,* 2004).

4.2 *Striga* Emergence

During the long rains of 2013, *Striga* emergence was significantly higher in non inoculated maize seeds than those inoculated with *F. oxysporum* f. sp. *Strigae* strains (Table 4, Appendix 6). Among the *Fusarium* strains, *Striga* emergence was significantly lower in FK5 and FK3 than in other strains in Bondo. The same trend occurred at Bar Olengo and Sagam. During the short rains, the same trend occurred except at Bondo where *Striga* emergence was not significantly different among the FK strains although was significantly lower than the control.

Generally, FK1 and FK2 had the highest *Striga* emergence compared to other FK strains. There was a *Striga* emergence reduction in FK3, FK4 and FK5.

Table 4: Mean *Striga* Emergence During the Growing Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

Treatments	Long rain season Sites			Short rain season Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	23.4	11.2	16.6	11	15.3	17
FK2	14.8	11.4	22.2	12.6	12.3	9.7
FK3	11.2	8.2	6.6	5.7	3.7	5.3
FK4	14.4	12	11.2	11	6.7	11
FK5	8.6	4.8	5.8	6	5.7	6.7
C	53	43.8	46.6	31.7	25.7	24.7
Mean	20.9	15.2	18.2	13	11.6	12.4
P value	0.00007	0.00002	0.00003	0.002	0.005	0.49
LSD ($_{0.05}$)	2.3	2.3	3.2	7.4	2.8	2.8 (NS)
CV (%)	7.8	9.4	8.4	7.4	7.1	5.8

CV- Coefficient of variance NS- Not Significant

In this study, all tested strains of *F. oxysporum* significantly inhibited emergence of *S. hermonthica* at Bar Olengo, Bondo and Sagam except in Bar Olengo during the short rain season. The significantly lower emerged *Striga* plants at Sagam site compared to Bar Olengo and Bondo sites may have been caused by higher microbial activity which inhibited *Striga* seed germination. Such results have been observed in previous studies where *Striga* population reduced due to application of *F. oxysporum f. sp. Strigae* isolates (Abbasher *et al.,* 1998; Ciotola *et al.,* 1995). Since the soils at Sagam are well drained, deep and friable (Kiplangat *et al.,* 2013), associating them with higher moisture retention provided a conducive environment for higher microbial activity.

It is also likely that the number of emerged *Striga* was controlled by soil fertility. This was evident from comparatively low number of emerged *Striga* at Sagam site (Appendix 6). These findings are supported by previous studies where the number of emerged *Striga* was correlated with soil fertility (Diallo *et al.,* 2007). In addition, some studies have demonstrated that the number of emerged *Striga* plants recorded aboveground is significantly correlated with the number of *Striga* attached to the roots in some cereal crops (Mourik, 2007).

Variability in climatic conditions such as rainfall has been shown to affect emmergence of *Striga* plants (Yonli *et al*., 2005). Erratic rainfall and high temperature experienced in Siaya County during the study period (Appendix 2) may have contributed to high *Striga* infection rates and hence low numbers of emerged *Striga* in the three sites; Bar Olengo, Bondo and Sagam. Irregular rainfall during the growing season led to low moisture content (Zahran, 2008) that reduced germination of *Striga.*

Additionally, Kroschel *et al., (*1996) found that the nature and amount of isolate administration to the sites affect efficacy of FK strains on *Striga*. Their results indicated that 90% *Striga* seeds germination was reduced when *F. oxysporum* fungus was applied during the seed conditioning phase. This later prevented the emergence by 98% when it was used as soil inoculum. Therefore, reduction in the rate of *Striga* seed plants can be affected by the nature and amount of inoculum application. The nature of seed inoculation used in this study would be less effective in controlling *Striga* emergence unlike when soil inoculation was done, leading to low reduction in *Striga* emmergence in Siaya County farm sites compared to the soil inoculation done by Kroschel *et al.,* (1996).

FK3 and FK5 strains performed better than other strains even though it is not understood how FK3 and FK5 had lower non significant *Striga* emergence than other FK strains in Bar Olengo site during the short rain season of 2013. The non significant different results in Bar Olengo site during the short rain season could have been due to microclimatic and edaphic factors and even other soil inherent pathogens having an impact on the activities of FK strains on *Striga* emergence.

FK3 and FK5 had the lowest significant *Striga* emmergence compared to other FK strains showing that FK3 and FK5 would be most appropriate strains for *Striga* emergence reduction and to curb its parasitic effects and menace in maize in maize fields in Siaya County.

4.3 *Striga* Infection Rates

During the long rain season of 2013, *Striga* infection rates was significantly lower in non inoculated maize seeds plots than those inoculated with *Fusarium* strains (Table 5). Among the FK strains, in Bondo site, FK4 was significantly lower in infection rates than other strains while FK3 and FK5 were significantly higher in infection rates on *Striga* than other *Fusarium* strains in Bar Olengo and Sagam sites. This was with an exception from FK1 and FK2 strains in Bondo site but they were significantly higher than FK4 and the non inoculated maize seeds plot (Table 5, Appendix 7).

During the short rain season, there was the same trend in infection rates of non inoculated maize seeds plots as compared to *Fusarium* treated plots as in long rain season. Among the *Fusarium* treated maize seed plots, FK3 and FK5 strains were significantly higher in infection rates in Bar Olengo, Bondo and Sagam sites than in other strains.

Table 5: Mean *Striga* Infection Rates (%) by F. oxysporum f. sp. Strigae Strains During the Growing Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

	Long rain season			Short rain season		
Treatments	Sites			Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	32.81	29.5	25.4	34.8	21.2	31.1
FK2	33.8	37.4	12.7	36.1	33.1	21.4
FK3	42.7	53.6	52.7	53.3	61.3	53.9
FK4	25	18.5	14.2	42.7	25.8	41.9
FK5	45.2	59.4	57.4	53.7	77.4	59.0
C	0	1.5	0.8	1.7	7.6	3.4
Mean	29.9	33.4	27.2	37.1	37.7	35.1
P value	0.01	0.00002	0.00003	0.001	0.00009	0.003
LSD ($_{0.05}$)	14.3	4.6	3.5	3.77	11.9	8.4
CV (%)	5.5	6.5	8.4	5.2	6.9	5.9

The significant infection rates in the local *F. oxysporum f. sp. Strigae* strains may be attributed to destruction of *Striga* seeds and wilting of emerged plantlets. On average, the efficacy of *F. oxysporum f. sp. Strigae* in controlling *Striga* was relatively low in Siaya County (i.e 53% - long rains and 63% - short rains) compared to foreign isolates carried out in west Africa where 75-90% were recorded (Abbasher *et al*., 1998) even though there was an efficacy of FK strains to infect emerged *Striga* plants; that is, an average of 53% long rain season and an average of 63% short rain season. On field to field basis, Sagam site recorded efficacy of 77% during the short rain season which was better than *F. oxysporum f. sp. Strigae* obtained from North Ghana and tested in Western Kenya by Avedi *et al*. (2014). Since previous studies have indicated that soil-inherent pathogens can suppress the effects of *Fusarium oxysporum* on *Striga* weed (Abbasher *et al*., 1998), it is likely that these played a major role in low rates of infection. The relatively low *Striga* infection rates could also be as a result of high *Striga* seed bank in the soil since the soils in the three sites are known to be highly infested by *Striga hermonthica.*

Due to negative effects and lack of efficacy shown by numerous research on foreign isolates (Avedi *et al*., 2014), current focus in biological control of *S. hermonthica* has shifted to utilization of local strains of *F. oxysporum.* Some of the tested local isolates of *F. oxysporum f. sp. Strigae* (*Foxy*-FK3) in Kenya have yielded promising results for both on-station and on-farm trial in the Western region (Okalebo *et al*., 2012; Beed *et al*., 2013). This study is also supported by local strains obtained from soils in western Kenya that were tested under green house trials that yielded more than 50% efficacy in controlling *Striga* (Kagot *et al.,* 2014).

Irregular rainfall during the growing season led to low moisture content that reduced germination of *Striga* and favoured *F. oxysporum f. sp. Strigae* infection rate (Yonli *et al.,* 2005). Although we did not monitor soil moisture content during the study period, the importance of soil moisture on pathogen development has been well documented in other studies with positive correlation between the rates of infection and soil moisture content recorded in Sudan soils (Zahran, 2008). In addition, variability in rainfall in both seasons and all sites might have favoured *Striga* infection by FK strains, especially at Bondo site where infection was high hence the observed variability in pathogens ability to suppress *Striga*. The observed differences in treatments between the seasons and sites may be due to environmental effects such as soil moisture, temperature or presence of other stimulants in the soil that were more favourable.

Low efficacy of *F. oxysporum f. sp. Strigae* in both seasons at Bar Olengo, pH of 4.0 and Bondo pH of 4.1 sites was attributed to low pH compared to Sagam site with a pH of 6.4. Acidic soil produces a poor soil-water-air relationship which may result in a poor plant growth and deficiency of iron or other micronutrients (Woomer *et al*., 2004; Zahran, 2008). This was not suprising since approximately 1 million hectares of land in Western Kenya is acidic with pH < 5.5 with consequences of P deficiencies (Woomer *et al.,* 2004). Therefore, presence of acidic soils in these sites might have affected the proliferation of the fungal strains in the soil and led to poor physical soil properties, which resulted in a reduced *Striga* control.

FK3 and FK5 strains were significantly higher in infection rates in Bar Olengo, Bondo and Sagam sites than other FK strains, where FK3 recorded an efficacy of 53% and FK5 an efficacy of 77% showing their high potentials to infect *Striga* weed.

4.4 Maize Height

There was no significant difference in maize height across long and short rain seasons, and also no significant difference between *Fusarium* treated plots and non inoculated maize seed plots and no significant differences among the inoculated maize seeds between sites though there was observed difference in plant height between non inoculated maize seeds and the *Fusarium* treated seeds (Table 6, Appendix 8). The control plots were generally lower in maize plant height except for the short rain season in Bar Olengo and Bondo sites when compared to the FK1 strains. Other strains performed better than FK1 and control maize seed plants except for FK2 and FK4 which were shorter than FK1 during the short rain season.

Table 6: Mean Maize Height (cm) During the Growing Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

Treatments	Long rain season			Short rain season		
	Sites			Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	126.7	117.7	58.3	68.6	87.5.1	77.5
FK2	136.5	129.3	72.3	73.1	85.6	76.3
FK3	128.36	142	95.3	74.3	105.2	81.5
FK4	146.4	123.5	88.7	73.9	86.2	74.2
FK5	142.57	135	101.3	85.7	106.9	80.9
C	114.7	94.7	57	70.5	78.2	79.2
Mean	132.5	123.53	78.79	74.3	91.4	78.3
P value	0.96	0.88	0.41	0.98	0.93	0.99
LSD ($_{0.05}$)	72.86 (NS)	67.49 (NS)	43.9 (NS)	44.06 (NS)	52.45 (NS)	52.7 (NS)
CV (%)	8.7	13.6	24	8	12.5	3.6

CV- Coefficient of variance NS- Not Significant

In the current study, maize plants in the three sites from seeds inoculated with *F. oxysporum f. sp. Strigae* strains and the non-inoculated ones had similar populations of *S. hermonthica*, but these maize did not significantly differ in most of the measured agronomic attributes; growth parameters such as plant height. Although previous studies have indicated that *Striga* weed infestation suppresses increase in height of cereal plants (Schaub *et al*., 2006; Yonli *et al*., 2005), there was no significant difference in maize plant height recorded in all sites in both long and short rain seasons among all *Fusarium* treated maize seeds plots and the non inoculated control plots. The non significant taller maize plants in the *F. oxysporum* strains treated plots compared to control plots may be due to other factors such as monocropping practices on soil, high temperatures, soil moisture content (Zahran, 2008), lack of or little effectiveness by the *Fusarium* strains (Avedi *et al*., 2014), low soil pH and even low soil

fertility rates in terms of soil N, P and even C percentages (Woomer *et al.*, 2004), *Striga* weed menace can be accelerated under low soil fertility and drought conditions (Atera *et al*., 2013). Deficiency of these nutrients may have been the dominant factor that led to lack of significant differences among five strains and the control plot at Bar Olengo, Bondo and Sagam sites. Furthermore, the obtained pH values for Bar Olengo and Bondo sites were below the required minimum (5.5) for maize growth and development (Kiplangat *et al.,* 2013). Since stunted growth is associated with acidity (Okalebo *et al.,* 2005), the observed low height in maize at Bar Olengo may have been driven by this phenomena.

There was better non significant performance in maize innoculated with FK strains than non inoculated control maize plots except at Bar Olengo during the short rain season. FK3 and FK5 inoculated maize plots performed better than other FK strains inoculated plots. It is not understood how the influence of microclimatic and edaphic factors effects on local FK pathogenicity on *Striga* on maize plant height in Siaya County yet without significant difference. There must be influence of other biotic and abiotic factors that do influence the performance of maize height (Kiplangat *et al.,* 2013) that should be assessed in Siaya County maize field sites.

4.5 Number of Maize Leaves

There was no significant difference in the number of leaves in long and short rain seasons, and no significant difference between *Fusarium* treated plots and non inoculated maize seed plots and no significant differences among the inoculated maize seeds between sites (Table 7, Appendix 9).

There was non significant difference in Sagam site where FK2 and FK4 generally did not improve in number of leaves as compared to long rain season. FK1 and FK2 were generally poor compared to the control plots during both long and short rain seasons across the sites. Generally FK3 and FK5 were better in number of leaves compared to other strains in long and short rain seasons except that FK4 had higher non significant number of leaves compared to FK3 in Bondo site in both long and short rain seasons.

Table 7: Mean Number of Maize Leaves During the Growing Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

	Long rain season			Short rain season		
Treatments	Sites			Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	12.5	10.25	8.75	10.65	10.3	9.8
FK2	11.5	11.25	8.75	11.15	9.57	9.67
FK3	11.75	10.5	10.5	10.9	10.72	11.2
FK4	12.25	10.25	9.75	11.4	9.9	9.97
FK5	12.5	10.5	10.5	11.47	11.8	10.85
C	12.25	10.5	9.25	8.97	10.25	9.5
Mean	12.13	10.54	9.58	10.77	10.43	10.16
P value	0.84	0.52	0.15	0.66	0.39	0.49
LSD ($_{0.05}$)	1.52 (NS)	1.16 (NS)	1.79 (NS)	2.63 (NS)	1.89 (NS)	1.71 (NS)
CV (%)	3.38	3.49	8.35	8.7	7.36	6.8

CV- Coefficient of variance NS- Not Significant

The number of leaves increased though not significantly in all the three sites. Some observations suggest that the effect of *Fusarium* species on the host plant cannot be attributed to the control of the parasite alone but also to interactions between the bio-agent; FK strains and the host plant (Avedi *et al.,* 2014). Since interactions between environmental factors, morphological, ecological and physiological variability have been known to affect the ability of *F. oxysporum* isolate to parasitize *Striga* (Yonli *et al.,* 2005), we found the pathogen to perform poorly in terms of the number of maize leaves during the growing season at the three sites. Microclimatic factors such as rainfall influences the growth vigor of the host such as the number of leaves and the number of emerged *Striga* (Baltus *et al.,* 1994; Yonli *et al.,* 2005). This was vivid in our study sites where the number of leaves varied non significantly between the long rains and short rain seasons. Although we did not monitor the local microclimatic condition during the study period, annual trend in rainfall and temperature within the County

(Appendix 2) aludes to a strong influence on the performance of maize plants during the growing seasons.

There was better performance in maize innoculated with FK strains than non inoculated control maize plots except at Bar Olengo during the short rain season. FK3 and FK5 treated maize plots performed better than other FK strains treated plots showing that they were more pathogenic to *Striga* weed in Siaya County farm sites than other FK strains. There is need to assess and monitor these factors influence on pathogenicity of FK strains in Siaya County since there is no data on microclimatic and edaphic factors influence on pathogenicity of FK strains tested on number of leaves of maize plants grown in Siaya County.

4.6 Maize Stover Weight

There was no significant difference in the stover weight in long and short rain seasons, no significant difference between *Fusarium* treated plots and non inoculated maize seed plots and no significant differences among the inoculated maize seeds between sites (Table 8, Appendix 10).

Among the non significant differences, stover weight was generally lower in control plots than FK strains in the long and short rain seasons and sites except for Bondo site where the control plots maize plants had higher stover weight than FK1 and FK4 in treatment plots long rain season and higher than FK2 during the short rain season. Generally FK3 and FK5 performed better than other strains in all sites in both long and short rain seasons except that FK3 performed poorly compared to other strains in Sagam site.

Table 8: Mean Stover Weight (g) at the End of the Growings Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

Treatments	Long rain season			Short rain season		
	Sites			Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	86.8	276.8	150.7	110.0	280.2	147
FK2	122.7	254.3	84.7	96.2	246.6	124.4
FK3	157.1	225.8	104.3	136.9	291.4	175.4
FK4	94.5	232.6	94.7	121.2	272.9	162.7
FK5	128.5	290.2	116	152.6	299.1	201.7
C	116.7	150.9	84.7	122.7	220.1	122.7
Mean	117.7	238.4	105.8	123.3	268.4	155.6
P value	0.13	0.051	0.5	0.5	0.6	0.2
LSD ($_{0.05}$)	14.6 (NS)	38.9 (NS)	43.1 (NS)	21.1 (NS)	31.2 (NS)	28.2 (NS)
CV (%)	21.43	20.76	23.66	16.07	11.09	19.68

CV- Coefficient of variance NS- Not Significant

Stover weight was not significantly different between seasons, sites and treatments. The relatively non significant low maize stover weight observed at Bar Olengo and Bondo sites could be associated with low nutrient retention of the soils. Low pH is associated with unavailability of soil micronutrients (Njui and Musandu, 1999), and may have therefore affected the growth vigour of maize plants at Bar Olengo and Bondo. Unevenly distributed precipitation affects growth of cereals crops and reduces stover weight (Gitari and Frisen, 2001). In addition, non significant difference obtained during the short rain season in stover weight signified the interactive effects of abiotic factors with tested local pathogens on maize performance. It is likely that the strains with improved non significant stover weight implied their persistence in the soil in subsequent season that conferred protection of maize and hence improved growth. Low stover weight in control plots was attributed to the effect of *Striga*

parasitism on local maize variety which had significantly high *Striga* emergence (Appendix 6) compared to the treated maize plots. Due to the high number of emerged *Striga* plants in the control plots, there was high level of parasitism leading to diversion of nutrients to the parasitic weed, *Striga* thus less biomass accumulation leading to low stover weight (Yonli *et al.,* 2005).

The non significant higher stover weight in the *F. oxysporum* strains treated plots compared to control plots may be due to other factors such as high temperatures, soil moisture content (Zahran, 2008), lack of or little effectiveness by the *Fusarium* strains (Avedi *et al*., 2014), low soil pH and even low soil fertility rates in terms of soil N, P and even C percentages (Woomer *et al.,* 2004), *Striga* weed menace can be accelerated under low soil fertility and drought conditions (Atera *et al*., 2013). Deficiency of these nutrients may have been the dominant factor that led to lack of significant differences among five strains and the control plot at Bar Olengo, Bondo and Sagam sites. Furthermore, the obtained pH values for Bar Olengo and Bondo sites were below the required minimum (5.5) for maize growth and development (Kiplangat *et al.,* 2013).

Generally, FK3 and FK5 performed better compared to other FK strains even though non significantly.

4.7 Maize Cob Weight

During the long rain season of 2013, there was no significant difference in cob weight in all the three sites; Bar Olengo, Bondo and Sagam between non inoculated maize seeds plots and *Fusarium* treated plots and no significant difference among the *Fusarium* inoculated plots (Table 9, Appendix 11).

During the short rain season of 2013, there was significant difference in cob weight in Sagam site whereby FK3 and FK5 were significantly higher than other FK strains and also significantly higher compared to non inoculated maize seeds in the control plots. Non inoculated maize seed plots had significantly lower cob weight in Sagam site compared to other inoculated maize seed treated plots. There was no significant difference between FK1 and FK2 in Sagam site on cob weight though they were significantly lower in cob weight than other FK strains but higher than in non inoculated maize seeds plots. There was no significant difference among non inoculated plots and inoculated plots in Bar Olengo and Bondo sites in cob weight in the short rain season.

Among the non significant differences in FK strains, FK3 and FK5 performed better than other strains in all sites and in both long and short rain seasons except that FK3 was lower in cob weight compared to other strains in Bondo site during the short rain season (Table 9, Appendix 11). In the long rain season, the non inoculated maize seeds plant were higher than FK2 in Bar Olengo site and higher than all the FK strains in Bondo site. During the short rain season, non inoculated maize plant seeds were lower in cob weight than other FK strains except in Bar Olengo site where it was higher than FK4 strain.

Table 9: Mean Cob Weight (g) at the End of Growing Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

	Long rain season			Short rain season		
Treatments	Sites			Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	125.7	157.4	101.4	151.7	175.1	142.5
FK2	123.1	160.2	94.8	148.2	174.5	146.8
FK3	128.7	172.8	132.3	132.3	197.5	165.8
FK4	116.0	186.0	114.2	149.2	184.3	135.5
FK5	120.3	199.9	140.7	152.3	196.3	158.9
C	138.5	155.7	97.5a	121.9	138.7	137.5
Mean	125.4	172	113.4	142.6	177.7	147.8
P value	0.14	0.17	0.2	0.2	0.008	0.3
LSD ($_{0.05}$)	8.8 (NS)	17.7 (NS)	12.2 (NS)	7.5 (NS)	6.5	19.7 (NS)
CV (%)	6.2	10.4	16.9	8.7	12.1	8.2

CV- Coefficient of variance NS- Not Significant

The significantly higher maize cob weight at Sagam site during the short rain season showed differences in FK strains tolerance and *Striga* infestation levels (Zahran, 2008; Yonli *et al.,* 2005). The significantly adverse effects of *Fusarium* spp. on *Striga* growth on maize performance were vivid by an improvement of cob weight at Sagam site in the short rain

season. On average, two local maize infected pathogen strains (FK3 and FK5) recorded significantly higher cob weight compared to other maize infected strains and the control. The low cob weight in the untreated plot was attributed to the effect of *Striga* parasitism on local maize variety in which control plots had significantly high *Striga* emergence compared to the treated maize plots. Due to the high number of emerged *Striga* plants in the control plots, there was high level of parasitism leading to diversion of nutrients to the parasitic weed *Striga* thus less biomass accumulation leading low cob weight. Although the insignificant differences in cob weight during the long rains season were majorly attributed to microclimatic factors (Gitari and Frisen, 2001), this might not have had significant effects in the short rains season in Sagam site due to the low *Striga* emergence observed and the general low moisture levels due to drought.

The non significant higher cob weight in the *F. oxysporum* strains treated plots compared to control plots may be due to other factors such as monocropping practices on soil, high temperatures, soil moisture content (Zahran, 2008), lack of or little effectiveness by the *Fusarium* strains (Avedi *et al*., 2014), low soil pH and even low soil fertility rates in terms of soil N, P and C percentages (Woomer *et al.,* 2004). *Striga* weed menace can be accelerated under low soil fertility and drought conditions (Atera *et al*., 2013). Deficiency of nutrients (N, P and C) may have been the dominant factor that led to lack of significant differences among five strains and the control plot at Bar Olengo, Bondo and Sagam sites. Furthermore, the obtained pH values for Bar Olengo and Bondo sites were way below the required minimum (5.5) for maize growth and development (Kiplangat *et al.,* 2013).

The relatively non significant low maize cob weight observed at Bar Olengo and Bondo sites could be associated with low nutrient retention of the soils. Low pH is associated with unavailability of soil micronutrients (Njui and Musandu, 1999), and may have therefore affected the growth vigour of maize plants at Bar Olengo and Bondo. Unevenly distributed precipitation affects growth of cereals crops and reduces stover weight (Gitari and Frisen, 2001). In addition, non significant difference obtained during the short rain season in stover weight signified the interactive effects of abiotic factors with tested local pathogens on maize performance. It is likely that the strains with improved non significant stover weight implied their persistence in the soil in subsequent season that conferred protection of maize and hence improved growth. Low stover weight in control plots was attributed to the effect of *Striga* parasitism on local maize variety which had significantly high *Striga* emergence (Appendix 6)

compared to the treated maize plots. Due to the high number of emerged *Striga* plants in the control plots, there was high level of parasitism leading to diversion of nutrients to the parasitic weed, *Striga* thus less biomass accumulation leading to low stover weight (Yonli *et al.*, 2005).

Generally, FK3 and FK5 performed better compared to other FK strains even though non significantly except at Sagam site during the short rain season where cob weight in FK3 and FK5 were significantly higher than other FK strains.

4.8 Maize Grain Yield

During the long rain season of 2013, there was no significanct difference in maize grain yield in all the three sites (Table 10, Appendix 12). During the short rain season of 2013, there was significant differences ($P<0.05$) in Sagam site where FK3 and FK5 were significantly higher in grain yield than other FK strains and Non inoculated maize seeds in Sagam site compared to the inoculated seeds. There was no significant differerence between FK1 and FK2 strains in Sagam site in maize grain yield but they were significantly lower than other FK strains though significantly higher than the non inoculated maize seeds in control plots in Sagam (Appendix 12). Among the observed differences, FK3 and FK5 performed better than other strains in terms of yield compared to other strains and yield in non inoculated plots. FK3 performed generally lower than other FK strains in Bondo site during the short rain season.

Table 10: Mean Maize Grain Yield (t/ha) at the End of the Growing Seasons in Maize Plots at Bar Olengo, Bondo and Sagam Sites in 2013.

Treatments	Long rain season Sites			Short rain season Sites		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	1.23	1.54	0.99	1.48	1.71	1.39
FK2	1.20	1.57	0.93	1.45	1.71	1.43
FK3	1.26	1.69	1.29	1.29	1.93	1.62
FK4	1.13	1.82	1.12	1.46	1.80	1.32
FK5	1.27	1.95	1.37	1.49	1.92	1.55
C	1.22	1.52	0.95	1.19	1.36	1.34
Mean	1.22	1.68	1.1	2.39	1.74	1.44
P value	0.2	0.1	0.2	0.2	0.008	0.3
LSD ($_{0.05}$)	0.07 (NS)	0.17 (NS)	0.12 (NS)	0.07 (NS)	0.06	0.19 (NS)
CV (%)	4.04	10.38	16.93	8.77	12.1	8.2

CV- Coefficient of variance NS- Not Significant

The significantly adverse effects of *Fusarium* spp. on *Striga* growth on maize performance were vivid by an improvement of the yield at Sagam site in the short rain season. Several studies have indicated that *S. hermonthica* has devastating effects on grain yield of susceptible maize by robbing its host of carbon, nitrogen, and inorganic salts (Kabambe *et al*., 2008). This diminishes the growth and photosynthetic capacity of cereal crops (Khan *et al*., 2008). Yields on the three farmer's fields were non significantly low. Based on highest performing strains, significant yield during the short rains (1.93 t/ha) for FK3 was obtained at Sagam site. This is due to FK5 and FK3 strains ameoliorating deficiencies in soil nutrients and its pathogenicity on *Striga* on maize yield at Sagam site during the short rain season. Although information on maize yield under fertilizer application in Siaya county is scarce, the observed non significant improved yield to a maximum of 1.5 t/ha in the three sites within

the control plot in this study could have resulted from the inorganic fertilizer that was applied at sowing (Gitari and Frisen, 2001; Okoth and Siameto, 2010; Kiplangat *et al.,* 2013).

Significant grain yield was observed at Sagam site during short rain season with all the tested *Fusarium* strains. On average basis, significantly higher yield was observed in FK3 and FK5 strains that yielded higher than other *Fusarium* strains and non inoculated maize seeds plots during the short rain season. Improvement in yield in Sagam site during the short rain was a result of persistent soil protection conferred by presence of the fungal strain in the soil and reduction of *Striga* seedling in the soil (Zarafi *et al.,* 2015). Higher level of *Striga* infestation affects crop performance in terms of growth and development, which ultimately affects the yield. Significant improvement in maize yield in treatment plots in Sagam site during the short rain season may have been caused by mycorrhizal association between maize plants and *Fusarium* strains and hence proving the pathogens ability to prevent further *Striga* distribution and infestation in the Sagam farm field as well as improving crop yield. Since soils around Wagai area have been considered as high potential in Siaya County (Njui and Musandu, 1999), high nutrient in the soil at Sagam site may also have contributed to the recorded high yields in both seasons.

The non inoculated maize seeds at Sagam site during the short rain season had significantly lower maize yield than the *Fusarium* strains treated maize seeds plots since the FK strains had low pathogenic effects on *Striga* emergence and hence lower infection rates on *Striga* possibly caused by other existing fungal pathogens in the control plots in the soil.

The reason for lack of significant improvement in maize grain yield at Bondo site may have been due to high rates of *Striga* infestation and parasitism (Yonli *et al.,* 2005) at the site evidenced from high rate of *Striga* emergence. Additionally, the soils in Bondo and Bar Olengo were Acrisols and Ferralsols (Atera *et al.,* 2013; Appendix 3), respectively, which may have contributed to the observed non significant low yield and the observed lack of consistency among the tested *Fusarium* strains at Bondo site. These soils were found to be acidic and with low fertility potential due to the recorded low nitrogen and phosphorus content (Appendix 3). Low yield in these sites may have been accelerated by the acidic nature of these soils since acidity causes N and P deficiencies as well as Al and Fe toxicity (Kiplangat *et al.,* 2013). Additionally, poor root development and delayed maturity which ultimately affects crop yield is a characteristic of acidic soils (Njui and Musandu, 1999; Gitari and Frisen 2001).

Generally, FK3 and FK5 performed better compared to other FK strains even though non significantly except at Sagam site during the short rain season where they performed significantly different than other FK strains. Little is known about the influence of microclimatic and edaphic factors on pathogenicity of local FK strains in Siaya County on grain yield tested in the three farm sites.

This study contributes to several years of research that have provided promising technologies, based on the biology of the parasite–host associations in dealing with the *Striga* weed (Kagot *et al.,* 2014). Findings of this study confirm the potential pathogenicity of *F. oxysporum f. sp. Strigae* on *S. hermonthica* in maize growing areas of Siaya County as reported by previous studies in parts of Africa (Avedi *et al.,* 2014). However, the pathogenicity varied significantly between tested *Fusarium* strains collected in different locations. *F. oxysporum* strains had significantly higher rates of *Striga* infection compared to the control. The tested strains differed in the rates of infection in which FK3 and FK5 were more pathogenic to *Striga* (Appendix 6 and 7) weed; FK3 had 53% efficacy while FK5 had 77% efficacy in controlling *Striga* weed in maize farm sites of Siaya County compared to other FK strains. *Foxy 2* from Ghana was not effective in controlling *Striga* in western Kenya (Avedi *et al.,* 2014) but was very effective in Ghana. This shows that locally isolated strains of FK are better in performance unlike foreign isolate which was not effective in controlling *Striga* in western Kenya, posing environmental risks as opposed to FK strains which are environmentally friendly, locally available and therefore cheap.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

All *Fusarium* strains were found to significantly affect *Striga* emergence rates and FK infection rates on *Striga* (Appendix 6 and 7) except in Bar Olengo site during the short rain season on *Striga* emergence. Based on their performance two strains of *F. oxysporum* (FK3 and FK5) which had infection rates <50% in all the three sites demonstrated the efficacy and suitability of *F. oxysporum* as a biocontrol agent against the *Striga* weed in Siaya County maize fields (Appendix 6 and 7). The tested fungal strains showed high level of efficacy on the *Striga* weed revealing a wide variety of local choices in developing a biological control against the weed.

Due to negative effects and lack of efficacy shown by numerous research of foreign isolates (Avedi *et al*., 2014), current focus in biological control of *S. hermonthica* has shifted to utilization of local strains of *F. oxysporum.* Some of the tested local isolates of *F. oxysporum f. sp. Strigae* in Kenya have yielded promising results for both on-station and on-farm trial in the Western region (Okalebo *et al*., 2012; Beed *et al*., 2013). This study is also supported by local strains obtained from soils in western Kenya that were tested under green house trials that yielded more than 50% efficacy in controlling *Striga* (Kagot *et al.,* 2014). Since the tested local strains are only adopted if field efficacy provides significant value to farmers and policy makers (Beed *et al*., 2013), FK5 (KALRO) and FK3 Siaya Agricultural Training Centre (ATC) strains are suitable for release to Siaya farmers as they will benefit them in the management of *S. hermonthica*.

5.2 Conclusions

Based on reduced *Striga* count per plot in each of the three sites and high infection rates on *Striga* plant, FK3 and FK5 were the most appropriate *F. oxysporum* strains for adoption by farmers in Siaya County. It is also expected that the use of local *F. oxysporum* strains will lead to reduction in *Striga* seed bank in the soil and hence greatly reduce the threat posed by the weed to maize farming and farmers' livelihoods as seen in all the three sites during the short rain season (Appendix 6 and 7). Generally, innoculation of maize with local FK strains before sowing resulted in fewer emerged *Striga* plants and affected *Striga* development through modification of the soil structure and functioning of the soil microflora which subsequently had negative effects on *Striga* growth. Therefore, it is possible that *Striga* menace in Siaya County farms could be controlled at sowing.

The tested FK strains performed differently in all the three sites. Significant effects of *F. oxysporum* strains was observed at Sagam site, followed by Bar Olengo site and finally the least effects at Bondo on the basis of *Striga* emergence and *Striga* infection rates by FK strains except at Bar Olengo during the short rains. Since the local *F. oxysporum* strains significantly affected *Striga* with different magnitude, which led to varying effects on maize performance in the three sites, these strains are field specific under varying geomorphic conditions (Appendix 3). Since all the tested *F. oxysporum* strains performed differently between the three sites, application of local *F. oxysporum* strains must be considered on a field to field basis.

Adoption of local agents in controlling *Striga* weed should be encouraged over foreign agents in order to reduce the environmental risks associated with introducing organisms from other areas (Avedi *et al.*, 2014). This is justified since biological control approach should give preference to a biological indigenous agent in order to reduce the risks associated with introducing organisms from other areas (Marley *et al*., 1999). FK strains had significant pathogenic effects on *Striga* emergence except at Bar Olengo during the short rain season and even the FK strains on infection rates on *Striga* weed (Appendix 6 and 7). FK3 and FK5 performed significantly different from other FK strains that showed their higher levels of efficacy as seen in Bar Olengo, Bondo and Sagam sites in terms of *Striga* emergence and infection rates.

There was evidence in better performance in maize as the amount of innoculum of FK strains increased in the soil and sites as seen in better yield during the short rain season as compared

to long rain season (Appendix 12). The *Fusarium* strains performed much better in Sagam site because of its higher soil nutrient availability and even its less acidic soils (pH of 6.4) that favoured maize growth (plant height and number of leaves) and even yield (stover weight, cob weight and even grain yield) as compared to Bar Olengo and Bondo sites (Appendix 3). Based on high plant height, number of leaves, stover weight, grain yield and cob weight, FK3 and FK5 were the most appropriate *F. oxysporum* strains for adoption by farmers in Siaya County. This study has revealed that application of local strains has the potential of decreasing damage done by S. *hermonthica* and significantly increasing maize yield in Siaya County, Kenya. Adoption of local *F. oxysporum* strains will increase maize yield in Siaya Countys' *Striga* infested fields from a dismal average of 0.95 t/ha to about 1.95 t/ha (Appendix 12). These results will no doubt bring renewed hope to farmers living under the perceived curse of *Striga*.

FK3 and FK5 were found to be effective in the three farmers sites in Siaya County in terms of maize performance; growth and yield (Appendix 8-12) due to the high pathogenic effects of FK3 and FK5 strains on *Striga* on growth and yield of maize hence bettering yield of maize in the three farm sites of Siaya County. It is therefore important to adopt FK3 and FK5 to improve in grain yield, better performance in Siaya County.

Maize plant heights, number of leaves and even stover weight that were not significant could be as a result of growth stimulators and other pathogens present in the soil that could have inhibited emergence of *Striga* and also resulted in higher plant heights and even number of leaves. Low yields that were not significant were as a result of other factors such as microclimatic factors such as rainfall patterns, low soil moisture content, low pH, low soil nutrient availability such as low Carbon, Nitrogen, Phosphorus (Woomer *et al*., 2004; Zahran, 2008) which can contribute to such non significant results.

FK5 and FK3 are therefore better *Fusarium* strains to be availed to Siaya County owing to their higher levels of efficacy in managing menace in farmers fields caused by effects of *Striga* on growth and yield of maize. They should be integrated together with other methods such as fertilizer application to improve soil nutrient in soil and soil amendments (Atera *et al*., 2013) that favour growth of maize such as soil pH improvement in Bondo and Bar Olengo sites which had acidic soils and low nutrients (Chemiat and Makone, 2015) available in soil (Appendix 3) thereby offering fields that are not suitable for maize growth to realize higher yields.

Although some pathogens have been shown to be unsafe to some crops (Zarafi *et al.,* 2015), the local *F. oxysporum* did not affect growth of inoculated maize seeds. This was evidenced from lack of significant differences in some agronomic traits such as height between the innoculated and uninnoculated maize. Lack of effects on maize plant height and number of leaves had also been found in other foreign isolates *F. oxysporum f. sp. Strigae* in many parts of Africa (Ciotola *et al*., 1995; Avedi *et al*., 2014). Other studies, had found *F. oxysporum* to have stimulatory effects on beneficial rhizosphere microbes (Avedi *et al.,* 2014). While some of the available studies on foreign *F. oxysporum* isolates (*Foxy 2*) had suggested the use of post-entry quarantine (PEQ) facilities to evaluate efficacy of exotic fungi to discourage possible negative effects (Avedi *et al.,* 2014), this is among the few studies to evaluate local strains of *F. oxysporum* on local maize variety in Kenya.

This study contributes to several years of research that have provided promising technologies, based on the biology of the parasite–host associations in dealing with the *Striga* weed (Kagot *et al.,* 2014). Findings of this study confirm the potential pathogenicity of *F. oxysporum f. sp. Strigae* on *S. hermonthica* in maize growing areas of Siaya County (Appendix 6 and 7).

5.3 Recommendations

Based on reduced *Striga* count per plot in each of the three sites, high FK infection rates on *Striga* plant andBased on high plant height, number of leaves, stover weight, cob weight and grain yield, this study recommends FK3 and FK5 as the most appropriate *F. oxysporum* strains for adoption by farmers in Siaya County to reduce the *Striga* menace from their farms.

Based on high maize plant height, number of leaves, stover weight, cob weight and grain yield, this study recommends FK3 and FK5 as the most appropriate *F. oxysporum* strains for adoption by farmers in Siaya County to increase maize growth and yield in their farms.

5.4 Suggestions for Future Research

Since this study did not reveal significant effects of FK strains on most agronomic traits, further studies are needed on tolerance of maize variety "Rachar" as well as the effects of *F. oxysporum* strains on agronomic traits in local maize in combination with other control methods. This could be carried out through integration of FK strains with other *Striga* management practices like soil nutrient amendments that favour growth and yield of maize, offering alkaline conditions in maize soil fields and other *Striga* control methods.

Considering the non significant differences in maize performance between the two seasons and different strains in all the sites, future studies should consider continuous monitoring of the effects of environmental factors such as soil moisture content, pH and temperature on local FK strains to infect *Striga* and how they in turn affect growth and yield in maize in maize growing sites of Siaya County.

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APPENDICES

Appendix 1: Field Sites

Plot layout at Sagam site

BLOCKS	TREATMENTS					
1	C	T1	T2	T3	T4	T5
2	T3	T5	T4	C	T1	T2
3	T5	T4	T3	T1	T2	C

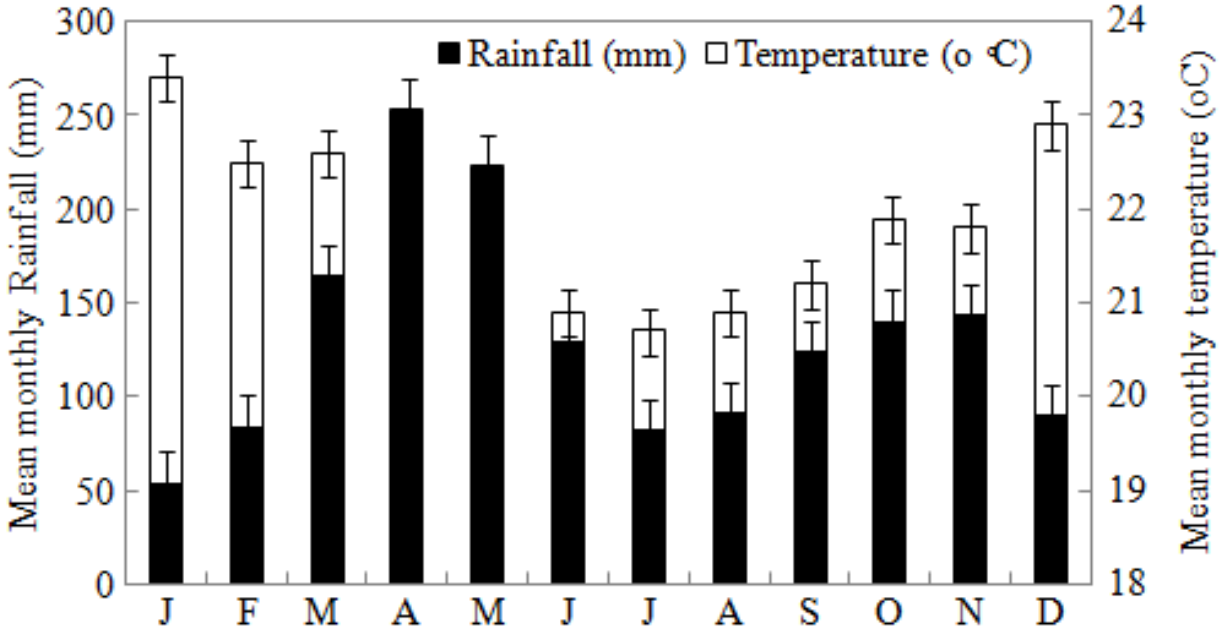
Plot layout at Bondo site

BLOCKS	TREATMENTS					
1	T2	T5	T3	C	T1	T4
2	C	T3	T4	T1	T5	T2
3	T5	T3	T2	T4	C	T1

Plot layout at Bar Olengo site

BLOCKS	TREATMENTS					
1	T3	T4	C	T2	T5	T1
2	T1	C	T2	T3	T4	T5
3	T4	T3	T5	C	T2	T1

Appendix 2: Rainfall and Temperature of Siaya County in 2013.



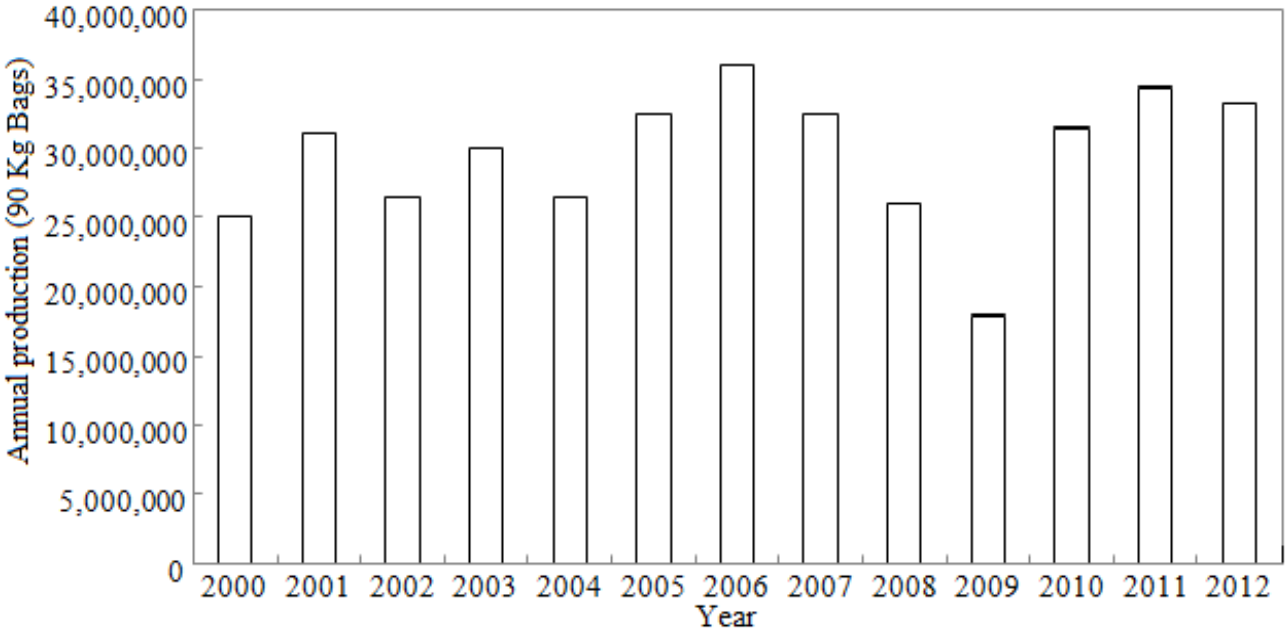
Appendix 3: Soil Properties of Three Study Sites in Siaya County

Site	Soil type	CEC (meq/100g)	pH	Total N(%)	Total P (mg/100)	Organic C (%)
Bondo	Acrisol	68.9	4.1	0.15	17.6	0.83
Sagam	Black Cotton	95.3	6.4	0.35	13.4	1.49
Bar Olengo	Ferralsols	38.2	4.0	0.17	23.4	1.12

Appendix 4: *Fusarium oxysporum* Phylogenic Tree

The strains were then identified as described earlier, by means of molecular and morphological techniques. These were the Fusarium species found to be associated with Striga, of which F. oxysporium appears to be the most predominant species. The Kenyan strains belongs to a single linage, as none of them were found to pair with any strains of the other 2 groups. For the phylogenetic studies, only foxy strains were used to draw up a maximum parsimony phylogenetic tree, using the Translocation Elongation Factor α-1 (TEF) gene region. The foxy strains collection were compared to various other foxy f. sp strains and the Kenyan isolates grouped together and formed a distinct clade. Based on the tree from the phylogenic tree, it is evident that the Kenyan strains FK1 to FK5 were genetically identical and belonged to a single Clade (Clade 1). This Clade constitutes fungal isolates identified as Fusarium oxysporium at 97% bootstrap support values in comparison to Genbank isolates. Slight intraspecific variations of some strains correlate well with phylogenetic species concepts, and do not indicate that they were two clades.

Appendix 5: National Annual Maize Production in 90 Kg Bags. (Source: Ministry of Agriculture, 2012).



Appendix 6: ANOVA for *Striga* Emergence Long Rain Season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	117	23.4	30.3
Row 2	5	74	14.8	60.2
Row 3	5	56	11.2	21.7
Row 4	5	72	14.4	7.3
Row 5	5	43	8.6	3.3
Row 6	5	265	53	132.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6807.5	5	1361.5	31.99765	7.26E-10	2.620654
Within Groups	1021.2	24	42.55			
Total	7828.7	29				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	56	11.2	48.7
Row 2	5	57	11.4	33.3
Row 3	5	41	8.2	32.2
Row 4	5	60	12	64.5
Row 5	5	24	4.8	3.7
Row 6	5	219	43.8	85.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5078.967	5	1015.793	22.73316	2.2E-08	2.620654
Within Groups	1072.4	24	44.68333			
Total	6151.367	29				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	83	16.6	21.3
Row 2	5	111	22.2	83.7
Row 3	5	33	6.6	25.3
Row 4	5	56	11.2	28.2
Row 5	5	29	5.8	6.7
Row 6	5	233	46.6	364.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5812.167	5	1162.433	13.17205	3.13E-06	2.620654
Within Groups	2118	24	88.25			
Total	7930.167	29				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	33	11	49
Row 2	3	38	12.66667	66.33333
Row 3	3	17	5.666667	9.333333
Row 4	3	33	11	37
Row 5	3	18	6	9
Row 6	3	95	31.66667	50.33333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1378	5	275.6	7.482353	0.002121	3.105875
Within Groups	442	12	36.83333			
Total	1820	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	46	15.33333	42.33333
Row 2	3	37	12.33333	30.33333
Row 3	3	11	3.666667	1.333333
Row 4	3	20	6.666667	2.333333
Row 5	3	17	5.666667	9.333333
Row 6	3	77	25.66667	112.3333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1004.444	5	200.8889	6.087542	0.004947	3.105875
Within Groups	396	12	33			
Total	1400.444	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	51	17	403
Row 2	3	29	9.666667	16.33333
Row 3	3	16	5.333333	1.333333
Row 4	3	33	11	91
Row 5	3	20	6.666667	40.33333
Row 6	3	74	24.66667	476.3333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	791.6111	5	158.3222	0.92376	0.498614	3.105875
Within Groups	2056.667	12	171.3889			
Total	2848.278	17				

Appendix 7: ANOVA for *Striga* Infection Rates

Long rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	98.43745	32.81248	144.2699
Row 2	3	101.4286	33.80952	33.33333
Row 3	3	128.3333	42.77778	73.14818
Row 4	3	75	25	625
Row 5	3	135.8971	45.29902	88.20941
Row 6	3	0	0	0

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4034.217	5	806.8434	5.022051	0.010313	3.105875
Within Groups	1927.922	12	160.6601			
Total	5962.139	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	88.52273	29.50758	4.13653
Row 2	3	112.2222	37.40741	128.4979
Row 3	3	160.988	53.66266	84.59005
Row 4	3	55.75758	18.58586	112.06
Row 5	3	178.2857	59.42857	98.69386
Row 6	3	4.626855	1.542285	3.430391

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7060.899	5	1412.18	19.64049	2.11E-05	3.105875
Within Groups	862.8175	12	71.90146			
Total	7923.716	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	76.25	25.41667	121.5208
Row 2	3	38.28572	12.76191	100.39
Row 3	3	158.3333	52.77778	39.81483
Row 4	3	42.69841	14.2328	185.4959
Row 5	3	172.2222	57.40741	72.01648
Row 6	3	2.451613	0.817204	2.003469

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7927.625	5	1585.525	18.25094	3.09E-05	3.105875
Within Groups	1042.483	12	86.87359			
Total	8970.108	17				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	**3**	**104.697**	**34.89899**	**2.303347**
Row 2	3	108.3261	36.1087	29.55349
Row 3	3	160	53.33333	311.1112
Row 4	3	127.8571	42.61905	306.2925
Row 5	3	161.1111	53.7037	133.7449
Row 6	3	5.263158	1.754386	9.233611

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5474.394	5	1094.879	8.292033	0.001362	3.105875
Within Groups	1584.478	12	132.0399			
Total	7058.872	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	63.53535	21.17845	126.7251
Row 2	3	99.58333	33.19444	143.1134
Row 3	3	184	61.33333	23.11114
Row 4	3	77.5	25.83333	102.0833
Row 5	3	232.2222	77.40741	420.1646
Row 6	3	22.93138	7.643792	43.91008

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10417.93	5	2083.585	14.55174	9.73E-05	3.105875
Within Groups	1718.215	12	143.1846			
Total	12136.14	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	93.33333	31.11111	28.7037
Row 2	3	64.28571	21.42857	107.7097
Row 3	3	161.6667	53.88889	128.7037
Row 4	3	125.7576	41.91919	877.7166
Row 5	3	177.1429	59.04762	47.16557
Row 6	3	10.26646	3.422153	11.62241

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6537.929	5	1307.586	6.529105	0.003736	3.105875
Within Groups	2403.244	12	200.2703			
Total	8941.173	17				

Appendix 8: ANOVA for Maize Height

Long rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	507	126.75	2270.917
Row 2	4	546	136.5	2337
Row 3	4	513	128.25	3221.583
Row 4	4	585	146.25	3730.25
Row 5	4	570	142.5	3751
Row 6	4	459	114.75	2096.917

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	**F crit**
Between Groups	2685	5	537	0.185091	0.96455	2.772853
Within Groups	52223	18	2901.278			
Total	54908	23				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	470.8	117.7	3424.36
Row 2	4	517	129.25	4056.25
Row 3	4	568	142	3642
Row 4	4	493	123.25	3752.25
Row 5	4	540	135	3624.667
Row 6	4	376	94	1799.333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5646.033	5	1129.207	0.333774	0.885861	2.772853
Within Groups	60896.58	18	3383.143			
Total	66542.61	23				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	233	58.25	916.9167
Row 2	4	289	72.25	958.9167
Row 3	4	381	95.25	1906.25
Row 4	4	355	88.75	1947.583
Row 5	4	405	101.25	1756.917
Row 6	4	228	57	763.3333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7256.208	5	1451.242	1.055459	0.41664	2.772853
Within Groups	24749.75	18	1374.986			
Total	32005.96	23				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	349.8	87.45	1618.437
Row 2	4	342.3	85.575	2133.883
Row 3	4	420.7	105.175	2380.703
Row 4	4	344.2	86.05	1913.297
Row 5	4	424	106	2561.807
Row 6	4	312.7	78.175	1086.883

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2623.867	5	524.7734	0.269229	0.924042	2.772853
Within Groups	35085.02	18	1949.168			
Total	37708.89	23				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	349.8	87.45	1618.437
Row 2	4	342.3	85.575	2133.883
Row 3	4	420.7	105.175	2380.703
Row 4	4	344.2	86.05	1913.297
Row 5	4	424	106	2561.807
Row 6	4	312.7	78.175	1086.883

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2623.867	5	524.7734	0.269229	0.924042	2.772853
Within Groups	35085.02	18	1949.168			
Total	37708.89	23				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	309.5	77.375	1097.596
Row 2	4	305.4	76.35	1404.15
Row 3	4	326	81.5	1739.907
Row 4	4	296.8	74.2	1318.887
Row 5	4	323.6	80.9	2173.027
Row 6	4	317	79.25	1153.83

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	157.4488	5	31.48975	0.021259	0.999773	2.772853
Within Groups	26662.19	18	1481.233			
Total	26819.64	23				

Appendix 9: ANOVA for Number of Leaves

Long rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	50	12.5	1.666667
Row 2	4	46	11.5	1
Row 3	4	47	11.75	1.583333
Row 4	4	49	12.25	2.25
Row 5	4	50	12.5	3
Row 6	4	49	12.25	0.916667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.375	5	0.675	0.3888	0.849984	2.772853
Within Groups	31.25	18	1.736111			
Total	34.625	23				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	41	10.25	0.25
Row 2	4	45	11.25	0.25
Row 3	4	42	10.5	0.333333
Row 4	4	41	10.25	0.916667
Row 5	4	42	10.5	0.333333
Row 6	4	42	10.5	1.666667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.708333	5	0.541667	0.866667	0.522283	2.772853
Within Groups	11.25	18	0.625			
Total	13.95833	23				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	35	8.75	2.25
Row 2	4	35	8.75	0.916667
Row 3	4	42	10.5	1.666667
Row 4	4	39	9.75	0.916667
Row 5	4	42	10.5	0.333333
Row 6	4	37	9.25	2.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.83333	5	2.566667	1.848	0.154092	2.772853
Within Groups	25	18	1.388889			
Total	37.83333	23				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	42.6	10.65	4.896667
Row 2	4	44.6	11.15	5.203333
Row 3	4	43.6	10.9	7.926667
Row 4	4	45.9	11.475	2.989167
Row 5	4	45.9	11.475	8.5425
Row 6	4	35.9	8.975	2.749167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.56708	5	3.513417	0.652496	0.663468	2.772853
Within Groups	96.9225	18	5.384583			
Total	114.4896	23				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	41.2	10.3	1.313333
Row 2	4	38.3	9.575	1.549167
Row 3	4	42.9	10.725	2.9225
Row 4	4	39.9	9.975	1.3425
Row 5	4	47.2	11.8	4.14
Row 6	4	41	10.25	1.53

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.80375	5	2.36075	1.106818	0.391201	2.772853
Within Groups	38.3925	18	2.132917			
Total	50.19625	23				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	39.2	9.8	1.98
Row 2	4	38.7	9.675	3.475833
Row 3	4	44.8	11.2	1.346667
Row 4	4	39.9	9.975	2.409167
Row 5	4	43.4	10.85	1.163333
Row 6	4	38	9.5	2.213333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.568333	5	1.913667	0.912114	0.495115	2.772853
Within Groups	37.765	18	2.098056			
Total	47.33333	23				

Appendix 10: ANOVA for Stover Weight

Long rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	260.6	86.86667	34.89333
Row 2	3	368.2	122.7333	2164.173
Row 3	3	471.2	157.0667	1523.293
Row 4	3	283.4	94.46667	677.6133
Row 5	3	385.6	128.5333	917.4533
Row 6	3	350.05	116.6833	135.2408

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9551.826	5	1910.365	2.102126	0.135399	3.105875
Within Groups	10905.34	12	908.7779			
Total	20457.16	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	830.53	276.8433	3976.238
Row 2	3	762.9	254.3	1509.39
Row 3	3	677.4	225.8	726.28
Row 4	3	697.8	232.6	3990.28
Row 5	3	870.6	290.2	3909.13
Row 6	3	452.8	150.9333	245.8033

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	36770.23	5	7354.047	3.073338	0.051537	3.105875
Within Groups	28714.24	12	2392.853			
Total	65484.48	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	452	150.6667	7225.333
Row 2	3	254.1	84.7	2147.23
Row 3	3	312.9	104.3	419.89
Row 4	3	284	94.66667	1989.333
Row 5	3	348	116	301
Row 6	3	254	84.66667	1301.333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9405.24	5	1881.048	0.84326	0.544517	3.105875
Within Groups	26768.24	12	2230.687			
Total	36173.48	17				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	330.1	110.0333	222.3433
Row 2	3	288.5	96.16667	883.7033
Row 3	3	410.8	136.9333	436.6533
Row 4	3	363.7	121.2333	72.06333
Row 5	3	457.9	152.6333	6276.503
Row 6	3	368.3	122.7667	108.6633

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5889.269	5	1177.854	0.883398	0.521218	3.105875
Within Groups	15999.86	12	1333.322			
Total	21889.13	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	840.53	280.1767	10987.64
Row 2	3	739.9	246.6333	970.3233
Row 3	3	874.2	291.4	4217.08
Row 4	3	818.8	272.9333	158.0133
Row 5	3	897.3	299.1	3377.08
Row 6	3	660.3	220.1	2637.97

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13312.22	5	2662.445	0.714811	0.624294	3.105875
Within Groups	44696.21	12	3724.684			
Total	58008.43	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	441	147	1116
Row 2	3	373.2	124.4	128.53
Row 3	3	526.1	175.3667	3081.223
Row 4	3	488	162.6667	6305.333
Row 5	3	605	201.6667	417.3333
Row 6	3	368	122.6667	1089.333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14084.39	5	2816.878	1.392454	0.294617	3.105875
Within Groups	24275.51	12	2022.959			
Total	38359.9	17				

Appendix 11: ANOVA for Cob Weight

Long rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	377.2	125.7333	36.42333
Row 2	3	369.5	123.1667	103.9033
Row 3	3	386.3	128.7667	62.76333
Row 4	3	348	116	12.81
Row 5	3	361	120.3333	111.0033
Row 6	3	415.6	138.5333	206.4533

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	908.8378	5	181.7676	2.044796	0.143885	3.105875
Within Groups	1066.713	12	88.89278			
Total	1975.551	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	472.2	157.4	322.09
Row 2	3	480.7	160.2333	52.80333
Row 3	3	518.6	172.8667	51.25333
Row 4	3	558.1	186.0333	422.9433
Row 5	3	599.7	199.9	765.03
Row 6	3	467	155.6667	1430.333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4783.458	5	956.6917	1.885445	0.170725	3.105875
Within Groups	6088.907	12	507.4089			
Total	10872.37	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	304.3	101.4333	68.76333
Row 2	3	284.5	94.83333	39.60333
Row 3	3	396.8	132.2667	29.06333
Row 4	3	342.5	114.1667	24.41333
Row 5	3	422.3	140.7667	3651.573
Row 6	3	292.5	97.5	35.91

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5538.456	5	1107.691	1.726574	0.203049	3.105875
Within Groups	7698.653	12	641.5544			
Total	13237.11	17				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	455.2	151.7333	325.3333
Row 2	3	444.5	148.1667	400.0033
Row 3	3	396.9	132.3	71.08
Row 4	3	447.7	149.2333	9.333333
Row 5	3	456.8	152.2667	548.1233
Row 6	3	365.9	121.9667	285.1033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2351.024	5	470.2049	1.721336	0.204223	3.105875
Within Groups	3277.953	12	273.1628			
Total	5628.978	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	525.2	175.0667	161.6233
Row 2	3	523.7	174.5667	54.90333
Row 3	3	592.5	197.5	6.88
Row 4	3	553	184.3333	470.0633
Row 5	3	589	196.3333	59.84333
Row 6	3	416.2	138.7333	838.1033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6955.131	5	1391.026	5.244483	0.008783	3.105875
Within Groups	3182.833	12	265.2361			
Total	10137.96	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	427.6	142.5333	810.9733
Row 2	3	440.5	146.8333	457.2033
Row 3	3	497.4	165.8	135.21
Row 4	3	406.5	135.5	67.48
Row 5	3	476.9	158.9667	63.37333
Row 6	3	412.5	137.5	448.81

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2204.184	5	440.8369	1.333815	0.314733	3.105875
Within Groups	3966.1	12	330.5083			
Total	6170.284	17				

Appendix 12: ANOVA for Maize Yield

Long rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	3.685287	1.228429	0.003477
Row 2	3	3.610057	1.203352	0.009918
Row 3	3	3.774196	1.258065	0.005991
Row 4	3	3.4	1.133333	0.001223
Row 5	3	3.820115	1.273372	0.004773
Row 6	3	3.669655	1.223218	0.000871

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.036501	5	0.0073	1.668487	0.21648	3.105875
Within Groups	0.052505	12	0.004375			
Total	0.089006	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	4.613449	1.537816	0.030745
Row 2	3	4.696494	1.565498	0.00504
Row 3	3	5.066782	1.688927	0.004892
Row 4	3	5.452702	1.817567	0.040372
Row 5	3	5.859139	1.953046	0.073026
Row 6	3	4.562643	1.520881	0.136532

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.456607	5	0.091321	1.885451	0.170724	3.105875
Within Groups	0.581217	12	0.048435			
Total	1.037823	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	2.973047	0.991016	0.006564
Row 2	3	2.779597	0.926532	0.00378
Row 3	3	3.876782	1.292261	0.002774
Row 4	3	3.346265	1.115422	0.00233
Row 5	3	4.125919	1.375306	0.348562
Row 6	3	2.857759	0.952586	0.003428

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.528674	5	0.105735	1.726572	0.20305	3.105875
Within Groups	0.734876	12	0.06124			
Total	1.26355	17				

Short rain season

Bondo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	4.447356	1.482452	0.031055
Row 2	3	4.342817	1.447606	0.038182
Row 3	3	3.877759	1.292586	0.006785
Row 4	3	4.37408	1.458027	0.000891
Row 5	3	4.462989	1.487663	0.052321
Row 6	3	3.574885	1.191628	0.027215

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.224417	5	0.044883	1.721334	0.204223	3.105875
Within Groups	0.312898	12	0.026075			
Total	0.537315	17				

Sagam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	5.131265	1.710422	0.015428
Row 2	3	5.116609	1.705536	0.005241
Row 3	3	5.788793	1.929598	0.000657
Row 4	3	5.402874	1.800958	0.04487
Row 5	3	5.754598	1.918199	0.005712
Row 6	3	4.066322	1.355441	0.080001

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.663903	5	0.132781	5.244484	0.008783	3.105875
Within Groups	0.303818	12	0.025318			
Total	0.967721	17				

Bar Olengo

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	4.177701	1.392567	0.077412
Row 2	3	4.303736	1.434579	0.043642
Row 3	3	4.859656	1.619885	0.012906
Row 4	3	3.971552	1.323851	0.006441
Row 5	3	4.659367	1.553122	0.006049
Row 6	3	4.030173	1.343391	0.042841

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.210401	5	0.04208	1.333814	0.314734	3.105875
Within Groups	0.378585	12	0.031549			
Total	0.588986	17				