MANAGEMENT OF STRIGA IN FINGER MILLET (*Eleusine coracana*) BY INTERCROPPING WITH DESMODIUM (*Desmodium intortum*)

BY

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DECLARATION

Declaration by the Student

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DEDICATION

It is with lots of love that I dedicate this work to my beloved husband; Dennis, my beautiful children; Linda and Loraine, my hero and late father Wilson and loving mother Wilkista.

ABSTRACT

Striga hermonthica (Del.) Benth is one of the major constraints affecting finger millet production in western Kenya causing significant yield losses. Research efforts have resulted in production of some improved finger millet varieties whose yield potentials remain unexploited due to susceptibility to Striga. High yielding improved finger millet variety P-224 is among the most susceptible varieties to Striga attack. Previous studies have shown positive results of intercropping maize with *Desmodium spp.* in efforts to control Striga and stem borers. Recent studies have also shown similar responses when a local finger millet variety was intercropped with *Desmodium spp.* This study was aimed at evaluating the potential Green leaf Desmodium (*Desmodium intortum*) to suppress Striga and improve yield when intercropped with improved finger millet varieties. Trials were set up on-station at Kenya Agricultural and Livestock Research Organization's Alupe centre (KALRO-Alupe) and on-farm at Okiludu in Teso South using a Randomized complete block design in a split-plot arrangement over two seasons (2013 short rains and 2014 long rains seasons). Treatments consisted of four improved finger millet varieties namely Gulu –E, U-15, P-224 and Okhale -1 intercropped with Green Leaf Desmodium (*Desmodium intortum*) and compared with finger millet mono crop plots. Varieties were assigned to main plots while the cropping system (intercropping and mono-cropping) to sub-plots. The most susceptible variety to Striga; P-224 was the control. Data was collected on Striga counts, plant height, basal tillers and yield. Soil analysis was carried out at the beginning and end of the trials to ascertain initial soil status and monitor any soil chemical changes due to the cropping system thereafter. Results in this study indicated no consistent evidence to show that intercropping finger millet varieties with *Desmodium intortum* suppressed Striga at the two sites during the two seasons tested. Striga density however differed across seasons. Lower Striga counts were observed during the long rains season (35.9 Striga plants/plot) plants while higher Striga counts (151.4 Striga plants/plot) were observed during the short rains season. Intercropping neither increased nor reduced finger millet yield. Finger millet yield however differed significantly across planting seasons where higher yield (1.1t/ha) was observed during the long rains season and low yield (0.6t/ha) during the short rains season. Finger millet yield was also influenced by soil nutritional status. Farmers at Alupe and Teso sub-counties are advised to consider planting finger millet during the long rain season when soil moisture is adequate and Striga density lower as this leads to improved yield. It may also be worthwhile to consider conducting the trial over a longer period of time with involvement of more farmers to further investigate the potential of *Desmodium intortum* for Striga suppression in improved finger millet varieties.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Finger millet is an important food crop in Western Kenya. It is a subsistence and food security crop that is important for its nutritive and cultural value. It also has a higher and stable market price when compared to other cereals like maize (Mgonja *et al*., 2007). Finger millet price ranges from KES 80 – 120 per kg while that of maize ranges from 30 – 50 shillings per kg in local markets. Its production is however constrained by weeds, pests and diseases among others. *Striga hermonthica* is one of the biggest constraints facing finger millet production in western Kenya (Atera 2010).

Striga, commonly known as witch weed, is the most economically important parasitic weed seed plant in the world (Atera *et al*., 2013). Striga infestation in Africa's agricultural economy causes a loss of 30-50% and affects about 40% of its arable land (Amudavi *et al*., 2007; Hearne, 2009). The average yield loss due to *Striga* in Kenya is 1.15, 1.10 and 0.99 tons per hectare for maize, sorghum and millet, respectively (MacOpiyo *et al*., 2010).

Farmers in western Kenya respond to the problem of *Striga hermonthica* through various traditional control methods. These methods include use of manure, hand weeding, uprooting and burning of Striga plants in affected fields. However, research findings show that these methods are insufficient to manage *Striga* once it is well established on a field (Woomer *et al.*, 2004).

Modern options to control *Striga* sp. such as crop resistance, intercropping cereals with legumes such as *Desmodium uncinatum* have been developed. One of the most promising Striga management strategies in susceptible cereal crops has been intercropping with *Desmodium sp.* The use of *Desmodium sp. w*as discovered by chance during development of a 'push – pull' strategy for control of Lepidopteran stem borers in maize in Kenya (Khan *et al*., 2000). In field trials in western Kenya, where *S. hermonthica* is highly prevalent, *D. uncinatum* and *D. intortum* were not only effective in controlling stem borers, but dramatically reduced infestations by Striga, leading to enhanced grain yields (Khan *et al*., 2006, 2008). This was explained by an allelochemical – mediated effect confirmed in a screen house experiment. Although the control of *S. hermonthica* by *Desmodium spp.* was discovered by chance, the work to date demonstrates the practical value of allelopathic weed control (Khan *et al*., 2008).

Between 2007 and 2008, the International Center for Insect Physiology and Ecology (ICIPE) scientists evaluated the potential of *Desmodium intortum*, a drought-tolerant desmodium species, for 'push–pull' application in finger millet variety local in western Kenya. The results of the study showed that the *Desmodium* species offered an effective control of both *Striga* and stem borers for finger millet (Midega *et al*., 2010). Results from this study indicated the highest finger millet yields as 943.8 kg/ha in the intercrop plots. This yield obtained in the local landrace plots was lower compared to the average of improved finger millet varieties ranging from 2,250-2,925kg/ha (Oduori 2008). Their potential is however constrained by the fact that some improved finger millet varieties e.g. P-224 are very susceptible to Striga while others are partially resistant. When variety P-224 is planted in areas with Striga more than 50% yield loss is observed (Oduori 2008). Intercropping these improved finger millet varieties with *Desmodium* *intortum* may help in managing Striga as well as improving finger millet yield for farmers in Striga infested areas of western Kenya. In addition to management of Striga, *Desmodium intortum,* a fodder legume, has been observed to be capable of fixing nitrogen into the soil. When used in intercropping systems with cereal crops the cereal benefits from this additional nitrogen hence improved yields (Khan *et al*., 2006).

Since farmers are already adopting some of these improved finger millet varieties as mono-crops, including an on-farm site that can be accessed by other farmers in experimentation may help in faster technology transfer. This is because the farmers will come together as a group, experiment together with the researcher and hopefully appreciate and adopt the technology that may eventually solve the Striga challenge they are currently facing.

The need for this study therefore was to improve finger millet yields in Striga susceptible varieties with high yield potential so that farmers in Striga hot spots can benefit from them.

1.2 Statement of the Problem

Striga infestation in improved finger millet varieties has frustrated some breeding efforts since the highest yielding finger millet variety P-224 is also the most susceptible to Striga attack and cannot be grown in areas with Striga infestation. The other partially resistant varieties have not been able to realize their full yield potential due to pressure from high Striga densities. Current management strategies such as manual removal of *Striga* plants before flowering has been found to reduce re-infestation, but is considered uneconomical since most of the damage is done underground even before the weed emerges. Farmers in western Kenya are therefore only left with the option of planting improved varieties that can tolerate Striga but still do not realize their highest yield potentials due to pressure under high Striga density.

Kenya Agricultural and Livestock Research Organization (KALRO) is disseminating improved varieties U-15, Gulu– E and Okhale -1 in finger millet growing regions in Western Kenya namely; Gucha, Busia, Kisii, Teso, Nyamira, Marakwet and Bungoma which were growing indigenous varieties in addition to variety P- 224 released in the 1990s. Teso sub-county commits the highest amount of land to finger millet cultivation (over 1,000 hectares). Coincidentally, Teso is a *Striga* hot spot and current production is being threatened (Mgonja *et al*., 2007). This study aims to utilize the potential of *Desmodium intortum*, when intercropped with improved finger millet varieties in suppressing germinating Striga, so as to improve yield in susceptible varieties with high yield potential..

1.3 Justification

In western Kenya, finger millet is considered important; mainly for food and income generation and also has a higher and stable market price when compared to other cereals (Takan *et al*., 2002; Obilana 2002). A socioeconomic baseline survey carried out in 2006 indicated the most important source of income for smallholder households in Busia and Teso sub-counties as sale of farm produce (66.2% of the respondents). The most important farm produce contributing to household income was finger millet (32.3%) followed by maize (29.2%), sale of other crops (18.7%) and sale of livestock/livestock products (17.2%) (Salasya *et al*., 2007).

Production of finger millet in its major growing areas is being affected by occurrence of pests and diseases hence significantly reducing yields and threatening food security. The most important of these is *Striga* which is most severe in Nyanza and Western parts of Kenya. Striga occurs in about 180,000 acres and results in crop losses estimated between KSh 800 and KSh 2,200 million per year (http://www.aatf-africa.org). In western Kenya, a survey conducted on 83 households revealed that 73% of the farms are infested with *Striga hermonthica* (Woomer and Savala, 2009). More specifically, another study carried out in Busia and Teso showed that 61-80% of the farms were infested with Striga (Ngesa *et al*.; 2015). Control methods such as use of resistant varieties, intercropping with fodder legumes developed by researchers have not been adopted by farmers. The reasons for non-adoption are that farmers are skeptical about the possibility of the methods to work (Atera 2010) thus are unwilling to test them. By researchers and farmers having an active linkage, technology transfer then becomes possible and faster (Atera *et al*., 2013). One way of achieving this could be including an on-farm demonstration during technology evaluation stage for farmers to participate and appreciate the benefits of the new technology. This way it becomes easier and faster to transfer the technology that helps solve their problem.

Striga's ability to produce large numbers of seed in a short period may lead to extremely severe infestation if no intervention is quickly sort. The finger millet dependent, food secure Teso sub-county could face severe food shortage. Therefore, an effective and sustainable intervention to Striga infestation needs to be sort for these regions to regain food security.

1.4 Objectives

1.4.1 Overall Objective

- To contribute to the management of S*triga* in finger millet growing areas of western Kenya and improve finger millet yields

1.4.2 Specific Objective

- To investigate the effect of intercropping *Desmodium intortum* with improved finger millet varieties on Striga density and finger millet yield.

1.5 Working Hypotheses

1. Intercropping improved finger millet varieties with *Desmodium intortum* reduces *Striga* and increases finger millet yield.

2. Striga infestation in improved finger millet varieties intercropped with *Desmodium intortum* varies from one variety to the other.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance, Distribution and Use of Finger millet

Finger millet is grown globally on over four million hectares and is the primary food and cash crop for millions of people in tropical dry land regions (Latha *et al.*, 2005). A 10% estimate of the world's 30 million tons of millet produced is finger millet (Dida *et al*., 2008). Finger millet is the most important Chloridoid grown in eastern and southern Africa and is a subsistence and food security crop that is valued for its nutritive and cultural value.

It is indigenous to eastern Africa where it is grown by small holder farmers. Uganda is the highest producer of finger millet in East Africa with 500,000 ha followed by Ethiopia with 238,000 ha and Kenya 65,000 ha. (National Research Council, 1996; Takan *et al.*, 2002). Other African countries cultivating finger millet include Sudan, Eritrea, Zimbabwe, Zambia, Malawi and Madagascar, Rwanda and Burundi. Outside Africa, the crop is grown on a larger scale in India, from the dry southern states up to an altitude of 2,300 m in the Himalayas (Obilana 2002).

Finger millet is consumed as staple food (78%), drinks and other uses (20%). Its use as livestock feed is still very low (2%). Finger millet is nutritionally superior to other cereals (Obilana 2002) in that its grain is rich in methionine (an amino acid that lacks in the diets of people living on starchy foods like cassava, plantain, polished rice, and maize meal). Finger millet has a better mineral nutritional profile (e.g. calcium > 5,000%; Iron and Manganese > 350%; and copper) and essential amino acids than maize (National Research Council, 1996). The grain's protein content (7.4%) is comparable to that of rice (7.5%) but the main protein fraction (eleusinin) has high biological value. It has high amounts of tryptophan, cysteine, methionine, and total aromatic amino acids, which are all important to human health and growth but are deficient in most cereals. For this reason, finger millet can be used to prevent malnutrition. Finger millet grain can be used in baking flatbread, preparing porridges and also for brewing beer. The straw is used as animal fodder. There is growing market demand for finger millet in Kenya and it fetches over double the price of sorghum and maize (Oduori, 2000). Improving its production would therefore greatly contribute to household income besides food and nutritional security.

2.2 Finger Millet Production Constraints

Finger millet farmers in western Kenya face a range of constraints including: declining soil fertility, high labor requirements for weeding, pests and diseases (Takan *et al*., 2002). Grain yields range from 500-750 kg/ ha on-farm, compared to 3,800-4,000 kg/ ha on research stations (Mgonja *et al*., 2007). This difference in yield is due to poor agronomic practices, use of low yielding varieties, pests and diseases. The most challenging of these constraints have been Finger millet blast disease and Striga infestation. Breeding efforts have produced some blast and Striga tolerant varieties but some of these do not yield as much as those varieties that are susceptible to Striga infestation. Finger millet yield loss due to *Striga* is 0.99 tons per hectare (MacOpiyo *et al*., 2010). Generally, it has been accepted that *Striga* control can be possible and sustainable if a wide range of technologies are combined into integrated *Striga* control (ISC) strategies to serve a range of bio-physical and socio-economic environments. The objective of ISC is to reduce *Striga* densities in the soil to avoid new plants emerging in the subsequent seasons (Douthwaite *et al*., 2007). Despite these challenges, finger millet is still widely used and valued; and new food products such as bread, malt, fodder, feed and baby food have industrial potential (Mgonja *et al*., 2007). The crop therefore has great potential as a food and for nutritional security.

2.3 Finger Millet varieties and their production challenges in western Kenya

Many farmers in western Kenya initially planted local finger millet varieties which gave low yields mainly due to low genetic yield potential and poor agronomic practices. The poor agronomic practices included use of broadcasting method of planting instead of row planting, no fertilizer use and inadequate weeding. Research intervention tested local varieties alongside improved varieties using proper agronomic practices and found improved varieties yielding higher than the local ones. Farmers are now adopting the improved finger millet varieties but some are facing challenges like susceptibility to Striga. Traditional Striga control methods such as hand pulling and weeding have not been effective. Modern Striga control methods such as intercropping cereals with Desmodium have been successful in suppressing Striga and improving yield. (Khan *et al*.; 2002). The potential of Desmodium to suppress Striga and improve yield in a local finger millet variety has also been reported on-station at ICIPE - Mbita point. (Midega *et.al*; 2010). However this has not been evaluated on improved finger millet varieties with higher yield potential than local varieties. The technology has not also been tested on-farm. Evaluating the potential of Desmodium to suppress Striga in improved finger millet varieties could be a solution to the Striga problem being experienced by finger millet farmers growing these varieties. The improved finger millet varieties have unique attributes that describe each one of them. A description of the attributes and challenges of improved varieties used in this study are summarized in Table 1.

Table 1 : Improved Finger Millet Varieties.

Variety	Abbreviated Name	Origin	Key traits
Okhale – 1	O K	Nepal	Purple plant pigmentation, High Yield (2,250kg/ha), Resistant to *Striga*, lodging and blast
P-224	P-224	Uganda	Green with no plant pigmentation, High Yield (2,925kg/ha), Susceptible to *Striga*, blast and lodging
U-15	U-15	Uganda	Purple plant pigmentation, High yield(2,475 kg/ha), Resistant to *Striga* and Blast, Short
Gulu – E	G E	Uganda	Green with no plant pigmentation, High yield(2,475 kg/ha), Resistant to blast and lodging

Source: Oduori, 2008.

2.4 Striga weed and its management

Striga, commonly known as witch weed, is a genus comprising of 28 species (Kamal, *et al*., 2001) of parasitic plants that occur naturally in parts of Africa, Asia, and Australia. It is an obligate parasite of roots and needs a living host for survival. Species that cause the most damage include *Striga asiatica, S. gesnerioides, and S. hermonthica. Striga hermonthica* (African witch weed) is parasitic to maize, millet, sorghum, sugarcane and rice. It is capable of significantly reducing yields, in some cases wiping out the entire crop. *Striga* affects the lives of about 100 million people in Africa and infests 40% of arable land in the Savanna region, with some severe infestations that have caused some farmers to abandon their land. (Khan *et al*., 2002). Affected plants show symptoms that include stunting, wilting, and chlorosis.

Each Striga plant is capable of producing up to 50,000 seeds, which may remain viable in the soil for over 10 years (Gethi *et al*., 2005). Striga seeds germinate in the presence of host root exudate and develop haustoria which penetrate host root cells. Host root exudates contain strigolactones, signaling molecules that promote Striga seed germination (Matusova, *et al*., 2005). The pathogen colonizes underground where it may spend the next 4-7 weeks before emergence, then it rapidly flowers and produces a large amount of seeds **(**Johnson, 2005). These seeds can be dispersed by wind, water and animal vectors.

Striga management strategies such as cultural and mechanical control, nitrogen fertilizers, resistant host crops have been tried. However, an integrated Striga control needs to be employed in order to achieve success with these methods. (Teka, 2014). *Striga* management remains quite challenging since it is an obligate hemi-parasite and most of its life cycle takes place underground. At this stage of its growth, it is completely parasitic on the cereal crop causing stunting. Once it emerges out of the soil, it develops foliage that is capable of photosynthesis and is able to continue growing on its own. If it is not detected before emergence, reducing crop loss becomes impossible (Johnson, *et al*., 2007).

The most effective Striga management strategy has therefore been to target its growth while still below ground. Planting a crop species in an infested field that will induce the *Striga* seeds to germinate but will not support attachment of the parasite has been successfully used. One such crop is *Desmodium intortum.*

Small scale farmers usually intercrop cereals with edible food legumes. This is because the intercrop offers additional benefit besides the main cereal crop. Intercropping improved finger millet varieties with *Desmodium intortum* will help manage Striga, improve soil nitrogen content as well as provide additional fodder to farmers in Busia and Teso. In addition, the reduced Striga pressure on finger millet and improved soil fertility will improve finger millet yield hence giving the improved varieties an opportunity to realize their full yield potential and contribute towards restoring food security in the region.

2.5 Green Leaf Desmodium (*Desmodium intortum*) and its allellopathic effect on Striga

Green leaf Desmodium is a perennial legume used for fodder and improvement in soil fertility. When cereals are intercropped with Desmodium in areas infested with Striga, dramatic reduction in the infestation is observed (Midega *et al*., 2010, Khan *et al.*, 2006). Desmodium increases the nitrogen content of the soil through biological nitrogen fixation, prevents soil erosion, conserves soil moisture and most importantly through its root exudates, Desmodium exerts an allellopathic effect on germinating Striga causing suicidal germination hence reduction of Striga seed in the soil (Khan *et al*., 2006). Desmodium roots release chemicals that undermine growth of Striga (allelopathic effect). The root exudates stimulate germination of *Striga* seeds and also inhibit post- germination growth of the parasite's radical (haustoria) – the part that attaches to the host plant. This is known as 'suicidal germination' and explains why desmodium can actually reduce the number of *Striga* seeds in the soil. Desmodium root exudates (isoflavanoids specifically di-C-glycoside of the flavones apegenin) have been identified with high activity in inhibiting *Striga* radical growth but without apparently causing adverse effects on cereals (Johnson *et al*., 2007). Previous studies on *Desmodium uncinatum* showed that its aqueous root exudates exhibited both Striga germination stimulation and post-germination radical growth inhibition (Tsanuo *et al*., 2003). It however is very susceptible to drought and easily dries up during prolonged dry spells and would not establish well in areas that receive limited amounts of rainfall. Drought tolerant *Desmodium intortum* seems a better choice as an intercrop for management of Striga in areas prone to periods of drought such as Teso since it also displays the same allelopathic effect on germinating Striga seed.

2.6 Effect of Desmodium on soil moisture conservation and soil fertility improvement:

Striga thrives well in dry environments with low nitrogen soils. Increasing the nitrogen content of the soil suppresses Striga germination. Desmodium is one of the most important cover cops used in enhancing soil fertility, preventing soil erosion and conserving soil moisture. (Tadesse *et* *al*.; 2016). Desmodium is a nitrogen fixing legume whose benefits are achieved during the second cropping season when it is cut back. Desmodium improves soil fertility through nitrogen fixation, natural mulching, improved biomass and erosion control. (Khan, *et al.;* 2011). The bushy growth of *Desmodium intortum* provides a micro-climate that conserves soil moisture making conditions for Striga germination unfavorable. Suppression of Striga germination, improved nitrogen levels and moisture conservation will give finger millet a chance to germinate, escape Striga attack, grow to its full potential and be able to produce higher yields.

2.7 Intercropping Cereals with Legumes as a weed management tool

Intercropping is the agricultural practice of cultivating two or more than one crop in the same space at the same time. It is an old and commonly used cropping practice which aims to match crop demands to the available growth resources and labor. The most common advantage of intercropping is the production of greater yield on a given piece of land by making more efficient use of the available growth resources using a mixture of crops of different rooting ability, canopy structure, height, and nutrient requirements based on the complementary utilization of growth resources by the component crops (Lithourgidis *et al*., 2011). Intercropping also reduces weed populations in cereal crops and increases per capita income (Zahid *et al.,* 2013). Plots with intercrops posses lower weed densities as opposed to their respective sole crops (Sharma and Banik, 2013). Weed biomass is also greatly reduced in intercrops compared to the respective sole crops (Hauggaard-Nielsen *et al.*, 2001). This makes weed management easier since it reduces the number of times weeding has to be done eventually lowering weeding costs.

Intercropping with legumes also improves soil fertility through biological nitrogen fixation as well as preventing soil erosion through greater ground cover as opposed to sole cropping. It also provides better lodging resistance for crops susceptible to lodging than when grown as pure stands, as well as reducing the amount of inputs required by plants through reduced crop fertilizer requirements since legumes act as a source of nitrogen in the system (Fustec *et al*., 2010).

Field observations in western Kenya depict farmers intercropping cereals with food legumes and this indicates that farmers can adopt intercrops with additional benefits besides the main crop. Some of these farmers have attempted to intercrop finger millet with maize in their fields but these two crops are both cereals hence not suitable for intercropping. This is because the two crops are attacked by the same weeds and pests (Striga and stem borer respectively) and one crop could be a source of pests for the other. They also compete against each other for nutrients, space and light resources hence the less competitive crop would have lower yields. The choice of *Desmodium intortum* as an intercrop in improved finger millet has potential benefits such as reducing Striga seed bank in the soil by preventing Striga plants from growing to maturity through allellopathy as well as increasing soil nitrogen content that would benefit subsequent crops. Past research has also shown that the two crops complement each other since there is less competition for growth factors because pasture legumes are weak competitors of soil nitrogen (Matusso *et al*.; 2012). Intercropping also helps in smothering weeds in crop fields by providing an above ground micro-climate that causes shading on the weeds below. This cuts off light from the growing weed hence suppressing it. The micro climate also increases soil moisture above the Striga seeds making germination conditions unfavorable. This way the negative effects of the weed on the main crop are reduced thus maximizing production. Intercropping finger millet with Desmodium could increase soil nitrogen content which would suppress Striga and improve finger millet yield.

The use of *Desmodium intortum* as an intercrop in improved finger millet varieties that are susceptible to Striga attack may be beneficial in Striga suppression, improving soil fertility, eventually allowing these varieties to achieve their full yield potential. This way, farmers in Striga infested areas will be able to benefit from formerly susceptible varieties with high yield potential. They will be able to have enough finger millet for home consumption and sale. Improved soil fertility will not only contribute to further Striga suppression but is also an ecological way of improving the Agroecological system. The harvested Desmodium will be used as livestock feed thus promoting increased milk production hence contributing to increased food security and income generation in households.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Geographical characteristics of study site

Field experiments were conducted at Kenya Agricultural and Livestock Research Organization (KALRO-Alupe) and Okiludu in Teso South situated 12 km and 30 km North of Busia town in Western province of Kenya respectively. Alupe lies on latitude 0.50^0N and longitude 34.13^0E while Teso South on latitude 0.53^0N and longitude 34.35^0E. The sites are Striga hot spots with Alupe as the on-station research site while Teso the on-farm demonstration site where participating group members would get a chance to be exposed to the new technology. The sites are classified as LM4 agro ecological zone and receive annual rainfall of 1,500 - 1,700 mm. Rainfall is bimodal and precipitation reaches its peak in April - May and is of a lesser degree in September - October. Mean annual maximum temperatures range between $27\text{-}31^0$c while mean annual minimum temperatures range between$15\text{-}18^0$c. The altitude of the area ranges from 1,130 to 1,220 meters above sea level. Soils are moderately deep reddish brown clay loam to light clays with a sub angular blocky structure classifying Alupe soil as Ferralsols and Teso soils Alfisols. (Nyaisava, 1980).

3.2 Field Trial

The experiment comprised of four improved finger millet varieties at two levels of cropping system for each variety. Variety was the main factor and cropping system (intercrop and mono-crop) the sub-factor. The main plots had improved finger millet varieties (Gulu-E, P-224, U-15 and Okhale-1). The most susceptible variety to Striga (P-224) was the control. These were laid out in a Randomized Complete Block Design with a split-plot arrangement. Treatments were replicated three times at each site giving a total of 24 plots per site (Figure 1). Plots measured 6 m x 6 m each.

Green leaf Desmodium was planted after every row of Finger Millet and around the experimental plots in three rows as guard rows. Green leaf Desmodium was sown by drilling three weeks before planting the finger millet. Finger Millet was spaced at 60 x15 cm.

Finger millet plots were applied with 20 kg P_2O_5 per ha at planting and 20 kg N per ha as a top dress. Weeding was done twice during the growing season; three weeks after emergence and three weeks later to reduce crop weed competition during finger millet's critical growing period. This was replicated on-farm where one famer hosted the trial and the other group members participated in implementation, maintenance and monitoring of the experiment.

Rep 1

Var 1 Des	Var 1 Mono	Var 2 Mono	Var 2 Des	Var 3 Des	Var3 Mono	Var 4 Mono	Var 4 Des

Rep 2

Var 3 Mono	Var 3 Des	Var 1 Des	Var 1 Mono	Var 4 Des	Var 4 Mono	Var 2 Mono	Var 2 Des

Rep 3

Var 4 Des	Var 4 Mono	Var 2 Des	Var 2 Mono	Var 1 Des	Var 1 Mono	Var 3 Des	Var 3 Mono

Figure 1 : Experimental layout.
KEY:

- Variety 1 = Gulu – E
- Variety 2 = U-15
- Variety 3 = P-224
- Variety 4 = Okhale-1
- Des = Finger Millet-Desmodium intercrop
- Mono = Finger Millet Mono crop
- Plot size 6 x 6 m with 1 m paths

3.3 Soil sampling and analysis for physical and chemical dynamics

Soil analysis was carried out at the beginning of the first season and at the end of the second season of the trials to determine the physical and chemical status of the soil before establishment and any changes thereafter that could have been influenced by treatment applications.

Soil samples were taken by random zigzag method, using a soil auger at a soil depth of 30 cm from KALRO-Alupe and Teso South. The soil was mixed to homogeneity and a composite sample of one kilogram soil taken from each site, placed in plastic sampling bags, labeled appropriately, sealed, and kept in a cool box. The samples were then delivered to KALRO–Kakamega's Soil Analysis laboratory and kept at room temperature. Part of the sample was sieved and analyzed for pH, organic carbon, available phosphorus, total nitrogen and particle size analysis as outlined in Okalebo *et al*., (2002). Soil available phosphorus was determined by the Mehlich double acid method using five grams of air dried soil. Percentage organic carbon was determined by the Walkey-Black oxidation method. (Walkey and Black,1934). Parkinson and Allen method was used in the determination of soil total nitrogen and the hydrometer method for the determination of the percentage sand, silt and clay.

3.5 Data collection and analysis

Data collection was carried out at two sites (Alupe and Teso) during two cropping seasons; Short Rains (September-December 2013) and Long Rains (March-August 2014) seasons. Alupe was the on-station site where the trial was managed by the researcher while Teso the on-farm site where the trial was managed by a farmer group. Parameters recorded during the finger millet growing seasons included total Striga counts per plot, number of basal tillers per plant, plant height at physiological maturity (grain milk stage) and dry grain yield (t/ha) of finger millet. Individual Striga plants were uprooted and counted and the total Striga counts recorded ten weeks after planting when the first Striga weeds started appearing and at physiological maturity when most of them had established. Basal tiller counts and plant height were conducted at physiological maturity. A 1 m x 1 m quadrant was tossed three times in each plot and a stone tossed within the quadrant to obtain the representative plant. A meter rule was used to measure the height from ground level up to the tip of the plant. Number of tillers was also recorded on the same plants. Where the representative plant had tillers, the main plant was measured for height and not the tillers. Averages of the plant heights and number of tillers of the three plants were then recorded.

The following model was used for data analysis.

$$\mathbf{Y_{ijklmn} = \mu + V_i + C_j + VC_{ij} + R_k + S_l + SC_{jl} + VCS_{ijl} + O_m + OC_{jm} + OV_{im} + OVC_{ijm} + SOCV_{ijlm} + \sum_{ijklmn}}$$

Where: $\mathbf{Y_{ijklmn}}$ **=** Finger millet Yield μ = Overall mean

V_i = The varietal effect due to the i^{th} level

C_j = The cropping system effect due to the j^{th} level

VCij = The interaction effect due to the i^{th} level of variety and j^{th} level of the cropping system.

R_k = The replication effect due to the k^{th} level

S_l = The Site effect due to the l^{th} level

VCS_{ijl} = The interaction effect due to the ith level of the variety, jth level of cropping system and the lth level of the site

O_m = The effect due to the m^{th} level of the season

OC_{jm} = The interaction effect due to the j^{th} level of the cropping system and the mth level of the season

OV_{im} = The interaction effect due to the m^{th} level of the season and i^{th} level of variety

OVC_{ijm} = The interaction effect due to the i^{th} level of variety, j^{th} level of cropping system and m^{th} level of the season

$SOCV_{ijklm}$ = The interaction effect due to the i^{th} level of variety, j^{th} level of cropping system, k^{th} level of the site and m^{th} level of the season

$\sum_{ijklmn}$ **=** Random error

Data collected for Striga, tillers, height and yield was analyzed using PROC ANOVA procedure of SAS software 9.1 and treatment means separated by Fischer's protected LSD at 95% confidence interval. Natural Log transformation of Striga counts; LStriga = Log_{10}(Striga + 1) was carried out before analysis due to the large variation in Striga counts recorded so as to stabilize the variance for analysis (Johnson *et al*.; 1997) and make meaningful comparison of treatments. A finger millet yield versus Striga count relationship diagram was generated to observe how yield was affected as the Striga density varied. Comparisons were made on the initial and final soil analysis results to monitor any physical and chemical changes that may have resulted from treatments in the trials.

CHAPTER FOUR

RESULTS

4.1 Striga density in Finger millet – Desmodium intercrops and Finger millet mono-crops

Results from the 2013 short rains season at Alupe and Teso indicated no difference in the suppression of Striga by *Desmodium intortum* in finger millet intercrop and mono-crop plots. There were no significant differences ($P \geq 0.05$) in Striga densities between intercrop and mono-crop plots as indicated by the transformed Striga density means in parenthesis shown in Table 2 and cropping system effect on Striga density shown in Appendix 2. There were also no significant differences ($P \geq 0.05$) in Striga density between varieties at both Alupe and Teso as indicated in Table 2 and Appendix 2.

Suppression of Striga by *Desmodium intortum* in intercrop plots during the 2014 long rains season did not differ from that observed in mono-crop plots. There were no significant differences ($P \geq 0.05$) in Striga densities observed between finger millet intercrop and mono-crops during the long rains season at both Alupe and Teso sites as indicated by the transformed Striga density means in parenthesis shown in Table 3. Striga density was not significantly affected by cropping system during the long rains season as indicated in Appendix 2. There was however a significant difference in Striga density between varieties at Teso site where varieties P-224, Gulu-E, and U-15 had significantly lower ($P \leq 0.05$) Striga densities than Okhale-1.

Table 2: Mean Striga densities (No. per plot) in finger millet intercrop and mono-crop plots at Alupe and Teso sites during the 2013 short rains season.

	Alupe					Teso				
Cropping System	**Varieties**					**Varieties**				
	Gulu-E	Okhale-1	P-224	U-15	**Mean**	Gulu-E	Okhale-1	P-224	U-15	**Mean**
Intercropping	37.3Aa (3.62)	74.4Aa (4.31)	194.4Aa (5.27)	68.7Aa (4.23)	**77.7a (4.35)**	126.5Aa (4.84)	561.2Aa (6.33)	221.4Aa (5.40)	206.4Aa (5.33)	**239.8a (5.48)**
Mono-cropping	232.2Aa (5.45)	223.6Aa (5.41)	137.0Aa (4.93)	46.5Aa (3.84)	**135.6a (4.91)**	79.8Aa (4.38)	450.3Aa (6.11)	214.9Aa (5.37)	235.1Aa (5.46)	**206.4a (5.33)**
LSD				**(2.23)**					**(1.97)**	
C.V. (%)				**27.5**					**20.8**	

Means with the same capital letter in a row or same small letter in a column denote no statistical significant difference at P ≥ 0.05

Note: Conclusions of differences in the actual Striga count means(not in parenthesis) were drawn from comparing the transformed means indicated in parenthesis using the LSD figure for the transformed means indicated in parenthesis too.

Table 3: Mean Striga densities (No. per plot) in finger millet intercrop and mono-crop plots at Alupe and Teso sites during the 2014 Long rains season.

	Alupe					**Teso**				
Cropping System	**Varieties**					**Varieties**				
	Gulu-E	Okhale-1	P-224	U-15	**Mean**	Gulu-E	Okhale-1	P-224	U-15	**Mean**
Intercropping	40.9Aa (3.71)	63.4Aa (4.15)	64.1Aa (4.16)	22.9Aa (3.13)	**44.3a (3.79)**	15.0Bb (2.71)	144.0Aa (4.97)	15.6Bb (2.75)	11.2Bb (2.42)	**24.8a (3.21)**
Mono-cropping	34.8Aa (3.55)	30.0Aa (3.40)	35.9Aa (3.58)	19.1Aa (2.95)	**29.1a (3.37)**	17.6Bb (2.87)	20.1ABab (3.00)	15.8Bb (2.76)	19.5ABab (2.97)	**18.2a (2.90)**
LSD				**(1.67)**					**(2.2)**	
C.V. (%)				**39.8**					**41.2**	

Means with the same capital letter in a row or same small letter in a column denote no statistical significant difference at P ≥ 0.05 Note: Conclusions of differences in the actual Striga count means(not in parenthesis) were drawn from comparing the transformed means indicated in parenthesis using the LSD figure for the transformed means indicated in parenthesis too.

4.2 Finger millet yield in Desmodium intercrop and Finger millet mono-crop plots

The 2013 short rains and 2014 long rains season results at both Alupe and Teso indicated similar finger millet yield in intercrop and mono-crop plots. There were no significant differences ($P \geq 0.05$) in finger millet yield between intercrop and mono-crop plots during the short rains season as indicated in Table 4. No significant difference ($P \geq 0.05$) in finger millet yield was observed between intercrop and mono-crop plots during the long rains season as indicated in Table 5. Finger millet yield across varieties was not influenced by cropping system during both short and long rains seasons as indicated in Appendix 4.

Table 4: Mean Yield (t/ha) in finger millet intercrop and mono-crop plots at Alupe and Teso sites during the 2013 Short rains season.

	Alupe					Teso				
Cropping System	**Varieties**					**Varieties**				
	Gulu-E	Okhale-1	P-224	U-15	**Mean**	Gulu-E	Okhale-1	P-224	U-15	**Mean**
Intercropping	0.82ABab	0.91Aa	0.54Bb	0.95 Aa	**0.81a**	0.40Aa	0.32ABab	0.26ABab	0.23ABab	**0.30a**
Mono-cropping	0.81ABab	0.99Aa	0.77ABab	0.88Aa	**0.86a**	0.40Aa	0.17ABab	0.13Bb	0.24ABab	**0.24a**
LSD				**0.29**					**0.22**	
C.V. (%)				**20.04**					**46.38**	

Means with different small letters in the column and capital letters in a row denote where there is a statistically significant difference (P ≤ 0.05)

Table 5: Mean Yield (t/ha) in finger millet intercrop and mono-crop plots at Alupe and Teso sites during the 2014 Long rains season.

	Alupe					Teso				
Cropping System	**Varieties**					**Varieties**				
	Gulu-E	Okhale-1	P-224	U-15	**Mean**	Gulu-E	Okhale-1	P-224	U-15	**Mean**
Intercropping	1.01 Aa	1.04A a	1.07 Aa	0.97A a	**1.02a**	1.27ABab	1.20ABab	1.16ABab	1.00abAB	**1.16a**
Mono-cropping	0.98 Aa	1.15 Aa	1.22 Aa	1.03 Aa	**1.10a**	0.91Bb	1.40ABab	1.41Aa	1.19ABab	**1.23a**
LSD				**0.34**					**0.45**	
C.V. (%)				**27.8**					**21.5**	

Means with different small letters in the column and capital letters in a row denote where there is a statistically significant difference (P ≤ 0.05)

4.3 Striga density, yield and related yield components in finger millet across seasons

Results of the combined analysis of both Alupe and Teso sites indicated a difference in Striga densities across the two seasons tested. More Striga emerged during the short rains season when compared to the long rains season. Striga density was significantly influenced by season as shown in Table 6 and Appendix 2. Striga density was significantly lower ($P \leq 0.05$) during the long rains season than during the short rains season where it was significantly higher. Tillering in finger millet was also different across the two seasons. The number of tillers in finger millet was significantly higher during the long rains season than those in the short rains season ($P \leq 0.05$) as indicated in Table 6 and Appendix 1. Plant height and finger millet yield differed across seasons as indicated in Appendices 3 and 4 respectively. Finger millet plants were significantly taller ($P \leq 0.05$) during the long rains season than those in the short rains season as indicated in Table 6. Finger millet yield was also significantly higher ($P \leq 0.05$) during the long rains season than in the short rains season as shown in Table 6.

Table 6: Mean Striga densities, finger millet yield and related yield components across planting seasons.

		Striga(no.)	Tillers(no.)	Plant height (cm)	Finger millet Yield(T/Ha)
Season	2013 Short Rains	151.4a (5.02)	1.88b	68.79b	0.55b
	2014 Long Rains	35.9b (3.58)	5.19a	75.65a	1.06a
Mean		93.65	3.53	72.22	0.81
LSD (0.05)		1.6(0.47)	0.31	2.72	0.09
P-Value		<0.001	<0.001	<0.001	<0.001
C.V (%)		25.4	21.4	9.2	27

Means with different letters in the column denote a statistically significant difference ($P \leq 0.05$)

4.4 Striga density, Finger millet yield and related yield components across sites

There was no significant ($P \geq 0.05$) difference in Striga density between Alupe and Teso as indicated by Striga count means in parenthesis shown in Table 7. Striga density was not influenced by site as indicated in Appendix 2. Finger millet plants at Alupe however had significantly ($P \leq 0.05$) higher number of tillers than those at Teso as shown in Table 7. Finger millet plants at Teso were also significantly taller than those at Alupe and Alupe recorded significantly higher finger millet yield than Teso as shown in Table 7. Tillering, plant height and finger millet yield were significantly influenced by site as indicated by Appendices 1, 3 and 4 respectively.

Table 7: Performance of finger millet and related yield components across sites.

Site	Striga (No.)	Tillers (No.)	Plant Height (cm)	FM Yield (T/Ha)
Alupe	79.0(4.37)a	3.81a	70.63b	0.88a
Teso	68.7(4.23)a	3.25b	73.82a	0.73b
Mean	73.9	3.53	72.23	0.81
LSD (0.05)	1.6 (0.45)	0.31	2.72	0.09
P - Value	0.5432	0.0007	0.0224	0.0018
C.V %	25.4	21	9.2	27

Means with different letters in the column denote where there is a statistically significant difference ($P \leq 0.05$)

4.5 Relationship between finger millet yield and Striga density across sites and seasons

A relationship plot generated for finger millet yield and Striga density results from the 2013 short and 2014 long rains seasons indicated a negative relationship between finger millet yield and Striga density. An increase in Striga density corresponded to a decrease in finger millet yield as indicated by the finger millet yield versus log Striga (transformed counts) relationship diagram (Figure 2). Teso site had the highest amount of Striga (Green color) during the short rains season which corresponded to the lowest finger millet yield. There was lower Striga density at Teso (Blue color) during the long rains season which corresponded to higher finger millet yield. Similarly, Alupe had more Striga (Black color) and lower finger millet yield during the short rains season while less Striga (Red color) and higher finger millet yield during the long rains season.

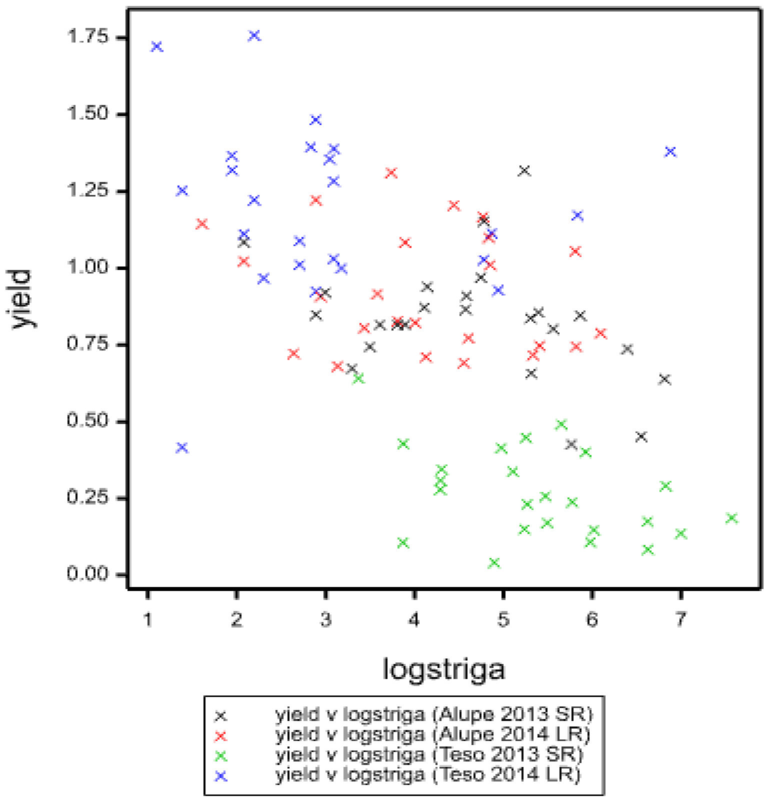

Figure 2: Relationship between finger millet yield and Striga density during the long and short rains seasons at Alupe and Teso.

4.6 Soil Physical and Chemical Analysis

There was a change in some soil chemical properties while others did not change at the two sites. Soil analysis results indicated that at the beginning of the experiment, Alupe had moderately acidic soils, with very low N, moderate organic carbon and low P while Teso soils were strongly acidic, with very low N, moderate organic carbon and low P contents. At the end of the trials, soils at Alupe were strongly acidic with very low P, low organic carbon and high N contents while Teso had moderately acidic soils with low organic carbon, very low P and low N as shown in Table 8. .

Table 8: Initial and final physical-chemical characteristics of top (0-20 cm) soil at Alupe and Teso.

	Sites			
Soil Characteristics	**Alupe**		**Teso**	
	Initial	Final	Initial	Final
Total N (%)	0.03 (very low)	0.4 (high)	0.03 (very low)	0.1(low)
P (ppm)	6.7- Olsen P (low)	0.3-Mehlic P(very low)	8.5- Olsen P (low)	0.3-Mehlic P(very low)
Organic C (%)	2.54(moderate)	1.3(low)	2.25(moderate)	0.9(low)
pH H_2O	5.8(moderate)	4.9(strongly acidic)	5.34(strongly acidic)	5.8(moderate)
Texture				
% Clay	20	37	37	22
% Sand	67	57	55	67
% Silt	13	6	8	11
Textural Class	Sandy loam	Sandy loam	Sandy clay loam	Sandy clay loam

CHAPTER FIVE

DISCUSSION

5.1 Factors influencing Striga density and Finger millet yield

a) Soil Moisture

Results in this study indicate that the density of Striga plants was lower in the long rainy season than in the short rainy season. Striga seed germinates only in the presence of germination stimulants (strigolactones). This may then implies that the amount of strigolactones available for Striga germination may have been higher during the short rains season than in the long rains season hence prompting more Striga seeds to germinate during the short rains season as opposed to the long rains season. One possible reason could be the long rains season within which the finger millet plants were exposed to 5 months of adequate rainfall (Appendix 5) may have brought about excess moisture in the soil that may have caused leaching of some strigolactones leaving behind low amounts for Striga germination. Gualbert *et al.*; (2004) carried out a study on sowing dates as a component of integrated Striga control for maize and sorghum. They observed that excess soil moisture can cause leaching of host root exudates (strigolactones) that normally trigger Striga germination which in turn reduces germination of *Striga hermonthica*. This implies that the amounts of strigolactones available in the soil to trigger Striga germination during the long rains season may have been lower than those available during the short rains season hence low Striga emergence during the long rains season as opposed to the short rains season where finger millet plants were exposed to only 3 months of adequate rainfall (Appendix 5). Therefore, only those Striga seeds that may have been exposed to the available strigolactones were able to germinate. A study carried out by Yoneyama *et al.;* (2010) on Strigolactones as germination stimulants for root parasitic plants (*Striga spp., Orobanche spp. and Phelipanche spp.*) revealed that, seeds of these root parasites would not germinate unless exposed to germination stimulants. This ensured that only seeds in the host plant's rhizosphere would germinate thus maintaining their seed bank in the soil.

Another explanation for the possible difference in strigolactones production across rainfall seasons would be related to the importance of strigolactones to plants. A question and answer article written by Smith, (2014) reveals that Strigolactones are important to the plants that produce them because they help these plants scavenge for nutrients during periods of environmental stress. The author explained that, many higher plants respond to environmental deficiencies by producing a higher amount of strigolactones which in turn stimulate hyphal branching in a fungal symbiont that forms Arbuscular Mycorrhizae (AM) on their host plants. This fungal hyphae spreads widely in the soil and helps to acquire mineral nutrients which the plant takes up. This may imply that the periods of low soil moisture during the short rains season within which the finger millet plants were exposed to only 3 months of adequate rainfall in this study, may have led to lower nutrient availability to the finger millet plants. Finger millet plants in turn may have produced a higher amount of strigolactones to help them scavenge for the nutrients. More Striga seeds existing in the soil responded to the available opportunity (germination stimuli) and germinated as well. On the other hand, because there was adequate water supply during the long rains season, finger millet plants were able to easily take up nutrients from the soil thus directed more energy to shoot development rather than producing additional strigolactones that would have stimulated hyphal branching in AM to help finger millet plants scavenge for more nutrients from the soil. The lower amount of strigolactones produced only triggered germination in Striga seeds that were close to them, resulting in lower Striga density during the long rains season when compared to the short rains season.

Ruiz-Lozano *et al.*; (2016) studied the correlation between AM root colonization, strigolactones levels and drought severity in lettuce and tomatoes. They suggested that under unfavourable conditions, plants might increase strigolactones production in order to promote symbiosis establishment to cope with the stress. Marzec *et. al.;* (2013) also studied the role of strigolactones in nutrient stress responses in plants and reported that the biosynthesis and exudation of strigolactones increase under phosphorus and nitrogen deficiencies. Brewer *et al.;* (2013) studied diverse roles of strigolactones in plant development and reported that plants that encounter nutritional deficiencies increase strigolactone production which changes root growth and promotes fungal symbiosis to enhance nutrient uptake. Another study by Pandey *et al.;* (2016) on emerging roles of strigolactones in plant responses to stress and development concluded that strigolactones are an important factor in helping plants overcome various stress conditions.

Unfortunately, since the finger millet plants in this study were in Striga infested areas, these high amounts of strigolactones produced could have also triggered high Striga germination leading to a higher Striga density during the short rains season when compared to the long rains season.

It was also observed in this study that finger millet yield was higher during the long rains season than in the short rains season. One reason for this variation in yield across seasons could be due to possible differences in adequate soil moisture availability during the crop's critical growing period. Soil moisture stress adversely affects growth and yield of crops especially cereals if it occurs during the critical growth stages (early vegetative, floral initiation, anthesis, fertilization and grain formation) (Kolay, 2008). The long rains season may have resulted to provision of adequate soil moisture during the critical growth stages of finger millet resulting in better yields than in the short rains season where finger millet plants may have experienced longer periods of moisture stress.

Since Striga density was lower during the long rains compared to the short rains season, this low density may have exerted less Striga pressure on the finger millet plants during the long rains season which in turn produced higher yield compared to the high Striga pressure exerted on the finger millet plants during the short rains season hence lower yields. This means that the higher number of Striga plants in the short rains season deprived many finger millet plants of available soil water and nutrients more than in the long rains season, leading to more stunting thus depressing yields more and vice-versa. Generally, a decrease in finger millet yield was observed as Striga numbers increased during this study. An increase in the number of Striga plants from 1 to 100 led to an average decrease in finger millet yield of 0.14 T/Ha. This increase in Striga density negatively affected finger millet yield.

Berhane (2016) reviewed the management of Striga and reported that the effect of Striga damage on crops is a reduction in yield. The author related the extent of yield loss to the incidence and severity of attack besides the host’s susceptibility to Striga and environmental factors. Babiker (2007) also studied Striga in Africa and reported that severe Striga infestation can lead to complete crop failure. A policy brief written by Van Mourik *et al.;* (2015) on *Striga hermonthica* seed bank in infested fields also indicated a negative linear relationship for sorghum yield loss and Striga seed density.

More tillers were produced during the long rains season compared to the short rains season during this study. This also implies that adequate water supply during the critical growing period is also an important factor in tillering of finger millet. Assuero and Tognetti, (2010) observed that low water availability affects tillering by reducing the number of potential sites for tillering in finger millet. More number of tillers which form heads eventually contribute to increase in yield hence the increase in finger millet yield recorded during the long rains season when compared to that recorded during the short rains season. Govindaraj et al., (2009) also found out that number of productive tillers positively associated with grain yield in pearl millet. This implies that there may have been more productive tillers produced during the long rains season as opposed to the short rains season thus contributing to an increase in finger millet yield during the long rains season.

Moisture alone cannot influence plant performance. Other factors such as available soil nutrients and crop management practices influence plant growth. The different finger millet yields observed at the trial sites could also be attributed to differences in site soil characteristics and possible differences in crop management practices. Soil analysis results conducted at the beginning and end of the trials indicated differences in the soil fertility status. There was an increase in soil nitrogen content (N) at Alupe from 0.03 % (very low) at the beginning of the trial to 0.4 % (high) at the end of the trial and Teso 0.03 % (very low) to 0.1 % (low) as determined by the Parkinson and Allen method.(Okalebo *et al.;* 2002). These changes in N levels observed at the end of the trial at the two sites may have been due to the effect of *Desmodium intortum* intercrop which could have fixed nitrogen in the soil when it was cut back after the first planting season. The final individual differences in N content between the two sites could have been influenced by differences in soil acidity where Alupe initially had moderately acidic soils while Teso strongly acidic soil. Biological nitrogen fixation reduces with an increase in soil acidity and this could be the reason why Alupe soils which were moderately acidic had higher nitrogen content than Teso soils which were strongly acidic. Bierder beck and Green, (2005) found out that the survival and activity of rhizobium (bacteria responsible for N fixation) in association with legumes, declines as soil acidity increases and amount of nitrogen is directly related to dry matter (yield). Observations from the current study may imply that Alupe soils which were moderately acidic may have had more rhizobium surviving resulting to higher nitrogen fixation than Teso soils which were strongly acidic which may have led to lower survival rates of rhizobium resulting in lower N fixation. The higher N content at Alupe may have led to higher finger millet yields than Teso whose lower yields may have resulted from lower N content.

Besides yield, Soil nitrogen also affects occurrence of Striga where an increase in the N content in a soil leads to reduction in Striga density as observed in a study by Larson (2009) who found out that N negatively correlated with the number of Striga seeds in the soil. The difference in N content observed between Alupe and Teso site did not bring about a significant difference in Striga density between the two sites as it did on finger millet yield. This may imply that for there to be a significant positive response of Striga density to soil N, there may have to be a significant increase in the amount of N in the soil. The observed positive response of finger millet yield to the change in N content at the two sites may indicate that changes in the amount of N in a given soil may trigger a yield response in finger millet.

Besides N, plants require adequate Phosphorus (P) for proper growth. Plants in soils with low P levels give low yields and vice versa. Soil analysis results rated both Alupe and Teso sites as having initial low levels of P (Alupe- 6.7 ppm and Teso – 8.5 ppm on the Olsen scale). At the end of the trials the two sites had similar final very low levels (0.3 on the Mehlic scale). This decrease in phosphorus content may have been brought about by removal of finger millet crop residue (straw) and grain from the field after harvesting. Since P may hane been taken up and utilized during crop growth and grain filling stage, most of it may have been utilized and stored in the finger millet grain as phytin (stored phosphorus) and in the finger millet straw hence may have left behind very low levels of P recorded at the end of the trials. A related study conducted by Thalakarathna and Raizada, (2015) also revealed that removal of crop residues by farmers from finger millet fields decreases K and P levels in the soil. Longer term studies by Kudra et al.; (2014) have shown P application having a significant reducing effect on Striga in sorghum though the mechanism behind this is still unclear. In this study, P levels recorded at both sites were very low by the end of the trial and may not have had any significant influence on Striga density. P availability in the soil is influenced by the level of acidity in the soil. Acidic soils have lower levels of P than near alkaline soils which have higher levels of P. Variation in finger millet yield at Alupe and Teso may be attributed to the differences in acidity levels at these sites. At the beginning of the trials Alupe had moderately acidic soils while Teso had strongly acidic soils. Duncan, (2002) found out that soil pH affects soil microbial activity leading to phosphorus fixation and phosphorus is most readily available between pH 6 - 7. When there is a reduction in soil pH, plant available phosphorus becomes tied up in aluminium phosphates making it unavailable for plant uptake. This then implies that the phosphorus applied to the finger millet plants at Teso may not have been readily available for plant uptake. This may have resulted in poor root formation and subsequent poor uptake of other nutrients required for proper plant growth. Alupe soils initially had a higher soil pH that was closer to the one required for favorable nutrient uptake and plant growth. There may have been adequate uptake of nutrients by finger millet plants at Alupe, resulting to higher finger millet yield than Teso where plants may not have received adequate nutrients for proper plant growth.

Another factor that influences crop yield is soil organic carbon. Soil analysis results at Alupe and Teso indicated a decrease in soil organic carbon levels from moderate (Alupe 2.54 % and Teso 2.25 %) to low (Alupe 1.3 % and Teso 0.9 %) at both sites. Soil acidity affects the amount of soil organic carbon in any given soil. The rate of decomposition of organic matter is slower in acid soils than in near alkaline soils. This could be the reason why Alupe which initially had moderately acid soils had higher soil organic carbon at the end of the trials than Teso which initially had strongly acidic soils that may have slowed down the rate of decomposition of soil organic matter hence lower release of organic carbon into the soil. This may then imply that the rate of decomposition of organic matter at Alupe may have been higher than that at Teso hence the higher amount of organic carbon at the end of the trials at Alupe than Teso. Soil texture also affects the amount of soil organic carbon present in a soil. Alupe had sandy loam soils while Teso had sandy clay loam soils. Clay particles in a soil trap soil organic carbon making it unavailable in the soil. This could have been the reason why Teso which had more clay particles, had lower soil organic carbon at the end of the trial when compared to Alupe. Similar results were observed by Chan et al., (2010) who observed that a sandy soil holds less soil organic carbon onto its particles than a clay soil. They also observed that soil acidity and aeration affect organic matter decomposition rates because micro-organisms do not survive well in acid soils. When organic matter decomposes it also releases other nutrients required by the plant for growth. This could have contributed to higher finger millet yields at Alupe than Teso since a possible higher rate of decomposition of organic matter at Alupe may have released more nutrients into the soil for plant uptake subsequently leading to better crop growth than Teso. This observed difference in nutrient level did not however reveal a significant effect on Striga density that may have a clear link to the amount of organic carbon in the soil at the two sites.

The trial at Alupe was completely researcher managed with all management operations conducted in a timely fashion. A possible difference in any of the instructed management practices such as proper land preparation and timely weeding on the farmer managed trial may have contributed to the low yields observed at Teso when compared to Alupe.

b) Cropping system

Results in this study indicated that Desmodium did not have a suppressing effect on Striga at both sites over the two seasons. This was contrary to the expectation from previous studies by Khan *et al.;* (2006) which indicated that Desmodium suppresses Striga when intercropped with cereals. The lack of variation in Striga density between intercrop and mono-crop plots in this study may be attributed to a possible high load of Striga seed in the soil and the short period of time the trial lasted. *Desmodium intortum* may have required more than the two seasons within which the trial was conducted to establish and have a significant reducing effect on emerging Striga plants. Previous studies carried out by Khan *et al.;* (2006) on the potential role of *Desmodium spp.* in the combined control of Striga and stem borers over three years confirmed that *Desmodium spp*. suppressed Striga and increased maize yield in all the six seasons tested and Striga suppression increased with each additional season. This may imply that if Desmodium is used as an intercrop in cereals over a longer period of time there could be more significant suppression of Striga than when planted for shorter periods. Results in this study did not also concur with Midega et al., (2010) who found out that Desmodium species offered an effective control for *Striga* in local finger millet during the one season of the short rains of 2010 when the trial was conducted.

Results from this study indicated no significant difference in Striga density at the two sites where the trial was conducted. Both sites were initially rated as having low N and at the end of the trials Alupe had a higher amount of N than Teso. Gebrelibanos and Assefa, (2015) conducted a study on nitrogen rate in relation to Striga counts and observed that a higher rate of nitrogen application in the soil correlated with lower Striga counts per plot and vice-versa.

No differences in finger millet yield were observed between intercrop and mono-crop plots during this study. This could be attributed to the lack of a positive effect (suppressing effect) of *Desmodium intortum* on Striga in the intercrop plots hence producing statistically similar number of Striga plants as in mono-crop plots. This may have resulted from similar stress factor (Striga pressure) on finger millet plants within intercrop and mono-crop plots hence producing statistically similar yields. This may imply that where there were no significant differences in Striga numbers between intercrop and mono-crop plots, no significant yield differences may be observed and vice-versa. *Kifuko-Koech et.al.;* (2012) studied the impact of *Desmodium spp.* and cutting regimes on the agronomic and economic performance of Desmodium-Maize intercropping and concluded that intercropping maize with Desmodium could only benefit farmers during later growing seasons. They had observed no significant differences in Striga density and yield between intercrop and mono-crop plots during the first two seasons of their study.

c) Finger millet Varieties

There was a difference in Striga density in some of the finger millet varieties tested in this study. The slight variation in the number of Striga plants emerging in plots with different finger millet varieties could be attributed to genetic differences in strigolactones production. Variety Okhale – 1 seemed to prompt higher Striga density than P-224, Gulu – E and U-15 which prompted lower but statistically similar numbers of Striga. Okhale-1 may have produced higher amounts of strigolactones which may have triggered higher numbers of Striga seed to germinate unlike the other varieties which may have triggered lower amounts of strigolactones hence statistically similar lower Striga density. Strigolactones are signalling molecules that are secreted by host plants into the rhizosphere where they act as germination stimulants for root parasitic plants. A study by Jamil *et al.*; (2011) quantifying the relationship between strigolactones and *Striga hermonthica* in rice indicated that genotype influenced strigolactones production. They observed some rice varieties producing more strigolactones than others. These results relate with another study by Muhammad et al., (2011) who observed that rice varieties that produced high amounts of strigolactones induced high *Striga hermonthica* germination, attachment and emergence. On the other hand, those rice varieties that produced low amounts of strigolactones induced less *Striga hermonthica* germination, attachment and emergence. Another study on sorghum genetic variability and resistance to *Striga asiatica* by Musimwa, (2005) revealed evidence of variability in the ability of sorghum varieties to stimulate germination of different Striga populations. From the observations in the three studies above, it may then follow that finger millet variety Okhale-1 may be genetically different in terms of strigolactones production (produces a higher amount of strigolactones) when compared to varieties Gulu-E, U-15 and P-224 which may be closely related in strigolactones production (may have the genetic potential of producing similar amounts of strigolactones).

Besides genetic differences in strigolactones production by plants, studies conducted by Callaway, (1992) revealed evidence of significant varietal differences in weed tolerance or competitiveness in 21 crops including potatoes, squash, beans, carrots, grain cereals, pulses and forage crops. This was because crop varieties vary in height, spread, canopy density and weed tolerance. He observed that tall or long-vine varieties with dense foliage compete more effectively against weeds than shorter varieties with less foliage. Among the four finger millet varieties studied here, variety Okhale-1 is the tallest finger millet variety with more foliage, followed by Gulu-E and P-224 while U-15 is a dwarf variety with the least foliage. These unique characteristics of Okhale -1 may have made it to compete effectively with Striga weed despite having the highest Striga density. Okhale -1 gave a statistically similar yield to the other finger millet varieties with lower Striga density.

No differences in finger millet yield were observed across the varieties tested in this study. This was because the yields reported in this study were average yields and not genetic yield potentials of the finger millet varieties tested. Lobell *et al*.; (2009) describe variety yield potentials as those yields that can be achieved when varieties are grown under favorable conditions without limitation to water, nutrients, pests and diseases. One yield limiting factor in this study was Striga which may have had a higher effect on varieties with high yield potential than on those with low yield potential hence the observed closely related yields among the finger millet varieties. For these finger millet varieties to be able to display their different individual genetic yield potentials, Striga may first have to be managed at the trial sites.

Although Okhale-1 prompted higher Striga germination, this did not significantly affect its yield which was very similar to the other three varieties. This ability of Okhale-1 to have no difference in yield with other varieties may indicate that Okhale-1 may have a higher competitive edge to Striga than Gulu-E, P-224 and U-15. This may then imply that variety Okhale-1 may be indeed tolerant to Striga infestation as reported by Oduori, (2008) who described variety Okhale-1 as being tolerant to Striga, blast and lodging. On the other hand variety P-224 which is the most susceptible variety to Striga had yields statistically similar to Gulu-E and U-15. This may imply that P-224 may be sensitive to a certain density of Striga infestation where its yield will be completely depressed implying that although it is described as highly susceptible to Striga, it may have some degree of tolerance to Striga under certain densities which may completely break down when Striga density exceeds this threshold.

Fernandez *et al*.; (2016) describe tolerant varieties as those varieties that are able to endure parasitic infection with minor losses on productivity. They explained in their review that tolerant plants exhibit some biochemical modifications which induce low performance of the parasite when attached. A related study by Abbes *et al.;* (2009) indicated that such tolerant plants achieve this low performance of the parasite by inducing high osmotic potential in their roots and dropping amino acid levels which reduces the flow of water and nutrients towards the parasite. This in turn limits the parasitic sink strength and yield losses due to the parasite. It may therefore be likely that variety Okhale-1 may have employed this mechanism of low performance by Striga on attachment thus only suffered mild yield loss in the current study. This may explain why despite variety Okhale-1 having high Striga density, its yield was statistically similar to the other varieties that had statistically lower Striga density.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 There was no consistent evidence in this study to indicate that *Desmodium intortum* suppressed emerging Striga plants in finger millet in the four varieties tested

6.1.2 Striga density in finger millet was lower during the long rains season and higher during the short rains season

6.1.3 Intercropping finger millet with *Desmodium intortum* neither increased nor reduced finger millet yield.

6.2 Recommendation

6.2.1 It is recommended that farmers in Alupe and Teso sub-counties should target planting their finger millet only during the long rains season when soil moisture is higher for longer periods as this suppresses Striga and results in better finger millet yield.

6.3 Further Research

6.3.1 It may be worthwhile conducting the trial over a longer period of time and with more farmers to further investigate the potential of *Desmodium intortum* for Striga suppression in improved finger millet varieties. The duration within which the trial lasted may have been too short to observe a positive suppressing effect of Striga by Desmodium.

6.3.2 A study on the amounts of strigolactones produced by finger millet varieties may be worthwhile to ascertain the observed tolerance of variety Okhale-1 to Striga.

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APPENDICES

Appendix i: Analysis of variance on effect of season, site, cropping system and variety on Number of Tillers.

Source of Variation	DF	SS	Mean square	F Value	Pr > F
Season	1	263.344	263.344	459.65	< .0001
Rep	2	2.688	1.344	2.35	0.1067
Season*Rep	2	0.438	0.219	0.38	0.6847
Variety	3	1.198	0.399	0.70	0.5585
Season*Variety	3	1.448	0.483	0.84	0.4774
Season*Rep*Variety	12	8.042	0.670	1.17	0.3311
Cropping system (CS)	1	0.844	0.844	1.47	0.2309
Season*CS	1	0.844	0.844	1.47	0.2309
Variety*CS	3	2.281	0.760	1.33	0.2765
Season*Variety*CS	3	0.448	0.149	0.26	0.8534
Site	1	7.594	7.594	13.25	0.0007
Site*CS	1	1.260	1.260	2.20	0.1445
Site*Season*Variety*CS	14	15.979	1.141	1.99	0.0391
Error	48	27.500	0.573		
Total	95	333.906			
C.V (%)			21.43		

Appendix ii: Analysis of variance on effect of season, site, cropping system and variety on Striga Count.

Source of Variation	DF	SS	Mean square	F Value	Pr > F
Season	1	49.750	49.750	41.62	< .0001
Rep	2	3.142	1.571	1.31	0.2782
Season*Rep	2	6.208	3.104	2.60	0.0859
Variety	3	9.785	3.262	2.73	0.0542
Season*Variety	3	2.509	0.836	0.70	0.5568
Season*Rep*Variety	12	27.791	2.316	1.94	0.0530
Cropping system (CS)	1	0.294	0.294	0.25	0.6220
Season*CS	1	2.333	2.333	1.95	0.1688
Variety*CS	3	1.283	0.428	0.36	0.7838
Season*Variety*CS	3	1.129	0.376	0.31	0.8146
Site	1	0.448	0.448	0.37	0.5432
Site*CS	1	0.335	0.335	0.28	0.5989
Site*Season*Variety*CS	14	48.989	3.499	2.93	0.0028
Error	48	57.375	1.195		
Total	95	211.371			
C.V (%)			25.43		

Appendix iii: Analysis of variance on effect of season, site, cropping system and variety on Plant Height.

Source of Variation	DF	SS	Mean square	F Value	Pr > F
Season	1	1130.254	1130.254	25.79	< .0001
Rep	2	160.656	80.328	1.83	0.1709
Season*Rep	2	306.093	153.046	3.49	0.0384
Variety	3	1681.811	560.604	12.79	<.0001
Season*Variety	3	164.635	54.878	1.25	0.3013
Season*Rep*Variety	12	1174.552	97.879	2.23	0.0246
Cropping system (CS)	1	30.600	30.600	0.70	0.4075
Season*CS	1	8.050	8.050	0.18	0.6701
Variety*CS	3	34.415	11.472	0.26	0.8526
Season*Variety*CS	3	1.111	0.370	0.01	0.9989
Site	1	243.844	243.844	5.57	0.0224
Site*CS	1	30.150	30.150	0.69	0.4109
Site*Season*Variety*CS	14	1738.853	124.204	2.83	0.0037
Error	48	2103.207	43.817		
Total	95	8808.230			
C.V (%)			9.17		

Appendix iv: Analysis of variance on effect of season, site, cropping system and variety on FM Yield.

Source of Variation	DF	SS	Mean square	F Value	Pr > F
Season	1	6.241	6.241	131.94	< .0001
Rep	2	0.010	0.005	0.10	0.9007
Season*Rep	2	0.000	0.000	0.00	0.9988
Variety	3	0.051	0.017	0.36	0.7820
Season*Variety	3	0.396	0.132	2.79	0.0504
Season*Rep*Variety	12	0.462	0.039	0.81	0.6345
Cropping system (CS)	1	0.029	0.029	0.62	0.4355
Season*CS	1	0.034	0.034	0.72	0.4006
Variety*CS	3	0.042	0.014	0.30	0.8283
Season*Variety*CS	3	0.019	0.006	0.14	0.9375
Site	1	0.516	0.516	10.91	0.0018
Site*CS	1	0.017	0.017	0.36	0.5508
Site*Season*Variety*CS	14	4.991	0.356	7.54	<.0001
Error	48	2.271	0.047		
Total	95	15.080			
C.V (%)			27.00		

Appendix v: Mean Monthly Rainfall (mm) for Busia County during 2013 short rains and 2014 long rains seasons.

Year	**Season**	**Month**	**Rainfall (mm)**
2013	Short rains	September	244.1
2013	Short rains	October	172.7
2013	Short rains	November	176.2
2013	Short rains	December	78.4
2014	Long rains	March	119.1
2014	Long rains	April	118.0
2014	Long rains	May	205.4
2014	Long rains	June	57.7
2014	Long rains	July	109.4
2014	Long rains	August	115.3

Source: Alupe Meteorological Station.