ROTATIONAL EFFECTS OF GRAIN AMARANTH *(Amaranthus hypochondriacus L.),* SOYBEAN (*Glycine max L.)* AND NITROGEN ON *STRIGA HERMONTHICA*INFESTATION AND MAIZE (*Zea maysL.*) PERFORMANCE IN SIAYA COUNTY.

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DECLARATION

DECLARATION BY THE STUDENT

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DEDICATION

I dedicate this work to my parents, the late Samson Kiprotich Kirui and Susan Kiprotich, my sisters and brothers who supported me to ensure that my dreams come true. Special dedication to my wife Lydia my children Emmanuel, Shalyne and Ebrahim who missed fatherly love while I was undertaking this work. I also thank my supervisors, Dr. Cornelius Serem and Prof. Wilson Ng’etich for their guidance throughout this work.

ABSTRACT

Maize is a dominant food crop in Kenya. It is a crop consumed in various forms by both urban and rural population and thus important in terms of food security. It is also grown for use as livestock feeds. Maize production in Siaya County is declining due to *Striga* weed infestation, soils degradation, pest infestation and unreliable rainfall. The aim of this study was to determine the rotational effects of grain amaranth, soybean and nitrogen fertilization on *Striga hermonthica* infestation and maize performancein *Striga* infested soils. On-farmtrials were conducted from August 2014 to July 2015 at Ugunja, Siaya county, western Kenya. The treatments included grain amaranth, soybean, maize and nitrogen. Grain yields and economic productivity of each crop was also determined. The maize test crop which was supplied with five levels of nitrogen, 0, 50, 100, 150 and 200 kg N ha^{-1}. Fifteen treatments were arranged as a split-plot in a randomized complete block design (RCBD) replicated three times. The main plot consisted of grain amaranth, soybean and maize while the subplots consisted of nitrogen rates. Maize without N fertilizer succeeding soybean resulted to 41.2% reduction on *Striga* count while maize without N fertilizer succeeding amaranth resulted in 34.4% reduction on *Striga* at 12WAP as compared to that produced from maize without N fertilizer succeeding maize in the rotation. The highest *Striga* number (31.44/m^2) at 12WAP was observed on maize mono-crop system without N fertilizer while the lowest Striga numbers (6.89/m^2) at 12WAP was observed on soy bean-maize crop rotation system. Though lower than soybean-maize rotation, amaranth-maize crop rotation at all level of N resulted in higher maize yield than in maize-maize crop rotation at similar levels of Nitrogen. Grain amaranth-maize rotation system interacting with 200kg N ha^{-1} resulted in 10.5% maize yield increase while soybean-maize rotation system interacting with 200kg N ha^{-1} resulted in 25.7% increase in maize yield as compared to maize-maize crop rotation system interacting with 200kg N ha^{-1}. Similarly, there was a significant increase in maize height and stover yield in grain amaranth-maize crop rotation system, soy bean-maize crop rotation system at all levels of N than in maize-maize crop rotation system. The study showed that crop rotation involving grain amaranth- maize and soybean –maize resulted in lower *Striga* population and higher returns of maize than maize-maize crop rotation system and hence this study recommend the adoption of amaranth- maize crop rotation system and soybean –maize crop rotation system by farmers as an efficient cropping system, strategy to reduce *Striga*, increase maize yield and improve nutrition of people in rural and urban.

TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

VEDCO	-Volunteer Efforts for Development Concerns, Uganda.
FAO	- Food and Agricultural Organization of the United Nations.
SSA	-Sub-Sahara Africa.
KALRO	-Kenya Agricultural & Livestock Research Organization.
FAOSTAT	-Food and Agricultural Organization Statistics Database.
CIMMYT	-International Maize and Wheat Improvement Centre.
IRM	-The Imazapyr-resistant maize.
NAS	-National Academy of Science.
AVRDC	-Asian Vegetable Research and Development Centre/World vegetable Research Centre.
KSTP 94	- Kakamega Striga Tolerant Striga Tolerant Population.
ANOVA	-Analysis of Variance
WAP	-Weeks After Planting.
GOK	-Government of Kenya.
IITA	-International Institute of Tropical Agriculture.
TTU	-Centre for underutilized crops.
ICIPE	-International Centre of Insect Physiology and Ecology.

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CHAPTER ONE

INTRODUCTION

1.1 Background information

The agricultural sector in sub-Saharan Africa is the key source of food, incomes, employment, and more often, foreign exchange. Agriculture in Sub-Saharan Africa accounts for 35 percent of Gross Domestic Product (GDP) employs about 62 percent of the population (Mugwe, 2014). In Kenya, agriculture is an important economic activity and accounts for approximately 26% of the GDP (GoK, 2010).

According to FAO (2006), cereal yield in SSA increased by only 29% between 1961 and 2005 compared to 177% in Asia and 144% in Latin America. The population grew by 216% in the SSA in the same period (United Nations Population Division, 2007). This meant that more production of the cereals needs to be done to feed the increasing population.

The major food crops grown in Kenya are maize, sorghum, sweet potatoes, wheat, rice, beans, finger millet and cassava (Atera *et al.*, 2012). In Kenya, cereal consumption was approximately 3.9 million tons (Ministry of Agriculture, 2010), while the production was 2.9 million tons in 2009. A preliminary forecast by FAO showed that Kenya needed to import 2.3 million tons of cereals to bridge a production deficit over 2011/12 cropping season. According to the 2017 Economic Survey, Kenya produced 37.1 million 90kg bags of maize in 2016 and had projected 40 million bags in the 2017season. This was because farmers increased the acreage due to better prices offered by the government.

Cereals play a central role in the food supply, but its production has lagged. The country’s food production capacity has not kept pace with the increasing food demand. The low yield recorded in the country is due to constraints of nutrient depletion, loss of organic matter, drought, weeds, and pest among others. Farmers, therefore, choose crops based on high yield and modern food consumption such as maize (Khan *et al*., 2014).

1.1.1 Maize

In the world cereal production, maize is ranked as the third major cereal crop after wheat and rice (Zamir *et al.,* 2013). According to Statista, (2015) the world domestic supply in 2013 was 960,053 tons. According to Kidist, (2013), Kenya, Tanzania, Zambia and Zimbabwe are among the main producers of white maize in Africa.

About 1.6 million hectares of land are under maize and 80% is grown by smallholder farmers (Mureithi *et al*., 2006), while Gitau (2009), estimated maize production by small scale farmers at 75% and large-scale farmers at 25%. Maize production in Kenya has been reducing over years with, soil degradation been reported to be the major contributor to this, (Ngome *et al*., 2012). Other causes of low yields include; pest attack, weeds, soil acidity, unreliable rainfall and lack of certified seeds. It is consumed in by 96% of the population and is also used as livestock feed as grain, hay and silage. It is composed of approximately 76 -88% of carbohydrate, 6-16% of protein, 4-5.7% fat and 1.3% of minerals. Jayne (2001), (Guantai*et al*., 2007) reported that Kenyans consume 2.7 to 3.1 million metric tons per year which translate to 98 kg of maize per person per year.

In 2017, maize production for Kenya was 3.19 million tons, against the country’s food security requirement of 3.6 million tons. This was a decline of negative 4 percent from the previous year. The decline was attributed to armyworm invasion in the key maize-producing regions and poor weather conditions for maize production characterized by rainfall shortages in maize-rich Uasin-Gishu and Trans-Nzoia Counties.

With the ever-increasing Kenya's population, the demand for maize and maize products far much exceeds the supply leading to need for importation as the case of2017 which led to higher price and call for government intervention through subsidizing.

1.1.2 *Striga hermonthica*

Weed control is one of the expensive agronomic practices in maize production. It increases the cost of production, lowers the value of land and reduces the returns to maize producers.

Striga hermonthica is a major constraint weed in production of important staple crops in Africa. *Striga* is a parasite weed commonly known as witchweed and is the most negatively economical parasitic weed in the world, affecting the livelihoods of more than 100 million farmers (Mignouna *et al.*, 2013).*Striga spp*. is the greatest biological constraint to food production in sub-Saharan Africa. The weed is estimated to affect the livelihoods of about 300 million people living in sub-Saharan Africa (Ejeta, 2007). Gressel (2004) estimated that 26million hectares in this area are infested by *S. hermonthica*and *S. asiatica*causing losses of about 10.7 million tons annually of cereal fields (maize, sorghum and millet). According to Cairns (2013), the yield of maize when *Striga* s*pp*. is present is as low as 1,000 kg

ha^{-1}, which displays some of the lowest yields in the world. Infested area and level are likely to increase in the near future because of the continued increase in cereal monoculture in some parts of Africa that has led to reduced soil fertility coupled with high moisture stress, and weeds,(Teka, 2014).

Striga is a specialized root-parasitic weed and deprives the host nutrients and water by connecting its haustoria to host xylem. *Striga* seeds, once preconditioned, will only germinate in the presence of germination stimulants, usually exuded by roots of the host, and some nonhost plants (Pickett *et al.*, 2010). Strigolactones are certainly the best studied and extremely potent inducers of *Striga* germination (Spallek *et al.,* 2013). Below ground and above ground life cycle and development of *Striga is* shown in Figure1 below.

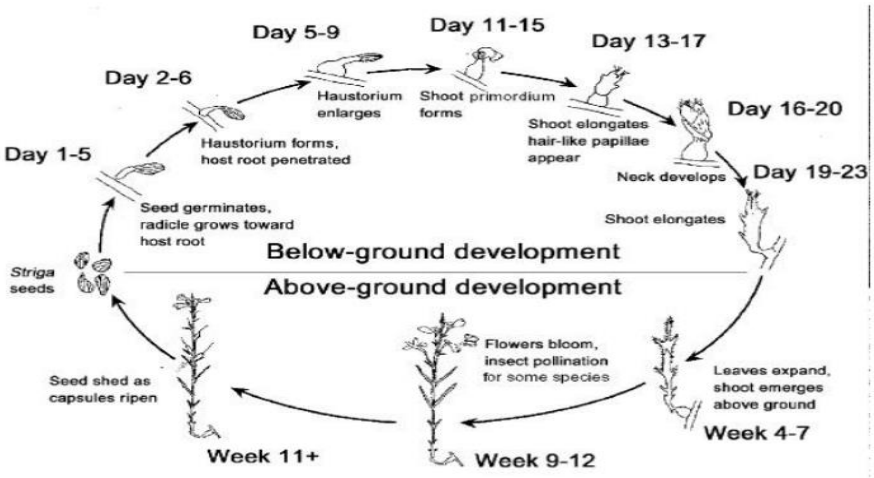


Fig 1: General life cycle of Striga species

Source: *Striga* Research Methods, (Berner, 1997).

The minimal length of the life cycle of the parasite, from germination to seed production comprises an average of 4 months. If the seedlings of *Striga* do not germinate, they can stay dormant in the soil for over 20 years (De Groote *et al.*, 2008). Estimated numbers of seeds produced per mature *Striga* plant vary widely and this depends on growing conditions, host species and host variety (Andrews, 1945; Parker& Riches, 1993; Rodenburg *et al*., 2006). There are about 28 species of parasitic *Striga* plants in Africa, Asia and Australia. They are classified in a family of

Orobanchacea (Gethi *et al*., 2007; Mahmoud *et al.,* 2013). Orobanchacea is the most economically important parasitic plants, a monophyletic group of root parasites with approximately 90 genera and more than 2000 species (Westwood *et al.,* 2010). The common species that attack maize, sorghum and millet and upland rice are *Striga hermonthica*affecting production mostly among the subsistence farmers, (Mohamed *et al.,* 2001; Westerman*et al*., 2007). The weed is common in soils low in plant nutrients especially Nitrogen, a phenomenon common with subsistence poor resource farmers in western Kenya. They are generally dispersed by water, wind, cattle, and man. Crops such as wheat, barley and Napier grass previously unaffected by *Striga* are now affected in the Sahel (Ejeta, 2007). The severity of *Striga* depends on ecological conditions, cropping systems, local cultural practices and farmers' skills on the ecology.

Control of *Striga* is only possible through a combination of efforts and technologies. Previous researchers have come up with ways to control the weed but have not been 100% effective due to the nature and dynamics of the *Striga* weed. Some of the efforts include; (1) herbicide coated maize seeds (2) intercropping maize and sorghum with *Desmodium* species, (3) biological control by *Fusarium oxysporum*, (4) inoculation of soil and host plants with mycorrhiza, and (5) marker-assisted selection to breed high levels of resistance into farmer-preferred sorghum varieties. This means that more work is needed to be done to eliminate the weed.

One of the recommendations of controlling *Striga* especially among small-scale farmers is the use of trap crops that stimulate suicidal germination of *Striga* seed in soil hence reducing *Striga* seed banks. This can be done through crop rotation or intercropping. Selection of a rotation crop should be based on socio-economic factors such as a market value of the selected crop in addition to whether it can stimulate *Striga* seeds to germinate.

According to FAO, (2006), only rice, wheat, maize and potatoes provide 60% of the global proteins and calories. Thus, in the process of identifying more trap crops for *Striga* control, considerations should be done on the high protein crops such as grain amaranth to supplement the above-mentioned crops.

1.1.3 Nitrogen

Nitrogen is one of the key nutrients needed for crop production; however, it is the most mobile, volatile and exhausting nutrients due to its ability to exist in different forms and its easy leachability (Mugendi *et al*., 2003). The use of N fertilizer to raise the limiting nitrogen content in most of western Kenya soils to assist in reducing the establishment of *Striga* weed. However, mineral fertilizers are too expensive for poor farmers. In a study done in Western Kenya, inorganic fertilizer to supply N and other plant nutrients on *Striga* infested fields increased the yields, but not enough to cover the cost for the extra amount of fertilizer needed (De Groote *et al.,* 2008).

Split applications of N fertilizer to cereal in monoculture and in the rotation have been suggested to increased yield, N use efficiency and N uptake efficiency (Lopez-Bellido *et al.,* 2006). Half of the recommended rate applied at two weeks after planting (2WAP) and the remaining half is applied at the beginning of stem elongation (6 WAP). The response of maize to applied N depends also on soil conditions such as soil moisture. The soil should not be dry or wet since this will interfere with crop absorption. Hence the interaction of climate and management causes variations in yields and crop N requirements.

1.1.4 Grain amaranth *(Amaranthus hypochondriacus)*

Grain amaranth is one of the oldest food crops in the world (Gigliola, 2012). It is herbaceous plant belonging to the family Amaranthaceae and it is grown mainly for if nutritious grains. However, its leave is consumed. The plant has green or red leaves and branched flower stalks (heads) bearing small seeds which are variable in colour from cream to gold and pink to shiny black. O‟Brien& Price, (2008) reported that grain amaranth originated from India and Ethiopia and was later taken to Incas in Mexico where it was used as staple food. Grain amaranth is cultivated for subsistence or commercial purpose in Kenya. However, it also grows naturally in farms and home gardens. Grain amaranth is gaining popularity in Kenya and according to Yongo, (2009), Western, Nyanza and Central provinces are the major growth and consuming areas.

According to Jacob (2005), at least, every ethnic group in Kenya has a name for amaranth; it is called *terere* in Kikuyu, *Mchicha* in Kiswahili, *Omboga* in Luhya *Ododo* in Luo, *Sikukuu* or *Chepkuratian* in *Pokot*, *Lookwa* or *Epespes* in Turkana, and *Ekwala* in Teso.

Amaranth can be used as a high-protein grain or as a leafy vegetable (Kariuki *et al.*, 2013). Grain contents fall within the following ranges: crude protein 12–19%, fat 5–8%, starch 62–69%, total sugars 2–3%, fibre 4–5% and ash 3–4% (Williams and Brenner 1995), carbohydrates 66.7–72.7%. It is rich in lysine, one of the important amino acids that play a vital role in the treatment and prevention of a disease known as *osteoporosis* that makes bones prone to fracture (Pisarikova, 2005). Amaranth grains can be consumed as cereals while the leafy part as a vegetable. According to Achigan-Dako, (2014), amaranth leaves and stems are steamed or boiled and used in soups or young leaves are eaten raw.

Several commercial products can be prepared from grain amaranth, including snacks, bars, breakfast cereals, bread and pasta. The leaves are rich in calcium, iron and vitamins A, B and C, but fairly low in carbohydrates. According to (Ng'ang'a *et al*., 2008), the dietary composition of amaranth can stimulate the body defence mechanism to retard the progression of the HIV/AIDS virus. Other medicinal values include; reducing or combating diabetes, hypertension, liver disease and haemorrhage (Kim *et al*., 2006). Other reports indicate that grain amaranth consumption facilitates the evacuation of placenta after birth as well as help in secretion of milk (Mwangi, 2006). Amaranth can also be used as animal feed. Research has shown that the use of cooked or autoclaved amaranth grain as chicken feed gives good production results (Yarger, 2008).

Several authors reported that the residues of some Amaranthus species might be efficient in weed control due to their allelopathic properties (Bradow and Connick, 1987; Connick *et al.,* 1989; Tejeda-Sartorius *et al*., 2008)

1.1.5 Soybean

Soybean is among the major industrial and food crop grown in every continent. The crop can be grown with low agricultural input and is compatible with other arable crops. Incorporating soybean in a crop rotation with other crops offers nutritional, income opportunities to farmers and boosts soil fertility through BNF (Nekesa*et al.*, 2011). Undisputed results on the use of soybean as a trap crop to control *Striga* weed has been obtained by many researchers (Sanginga *et al.*, 2003; Odhiambo *et al.,* 2011). Hence, it was chosen for comparison with grain amaranth.

Previous studies have shown soybean rotation has “residual effects” (nitrogen fixed) and contributes more benefits to maize than other cropping systems (Yusuf *et al.*, 2009).

1.1.5 Crop rotation

Crop rotation is probably among the cost-effective ways to reduce *Striga* infestations and increase maize yields and income considering the limited resource of small-scale subsistence farmers in sub-Saharan Africa. In the western part of Kenya, the increasing food demand and decreasing land sizes as led to continuous cereal monocropping, which has replaced crop rotation and fallowing. This has resulted in soil mining and consequently increased *Striga* population which is associated with low soil fertility. Well-Planned crop rotation is known to replenish soil fertility especially when legumes are included.

The selection of crop for rotation in control of *Striga* should be based on suitability to the ecological conditions of that particular area and its potential to trap the *Striga* weed.

The objective of this study was therefore to evaluate the ability of grain amaranth to control *Strigahermonthica* through suicidal germination compared to tested soybean and N fertilizer, grain yields of maize and economic productivity with the objective of determining the efficacy of the crop rotation. It was also meant to obtain knowledge in production and utilization grain amaranth, a neglected, disregarded, underexploited plant species, or sometimes called alternative crop. Alternative crops are plant species that were used traditionally for food, fibre, fodder, oil or medicinal properties. Such have an under-exploited potential to contribute to food security, nutrition, health, income generation and environmental protection.

1.2 Statement of the Problem

Maize is a staple food for over 90% of the country’s population (Wambugu *et al*., 2012). Other than the source of food, maize provides and income to many.

Unfortunately, the area under which maize is grown especially the western part of Kenya is heavily infested by *Striga*, reducing yields of farmers by 30-100% (Bruce, 2010). Among the several factors, which include unreliable rainfall, diseases and pest, the most critical for the low yield of maize appear to be the weeds competing with the crop for nutrients, water, sunlight and space.

Western Kenya has a high population density and the majority of the inhabitants are poor, (Country STAT Kenya, 2011). Maize is the most important food and cash crop in this area. Farmers grow improved maize varieties with a potential yield of 10 ton/ha but realize less than 1.0 tonsha^{-1}. Yields as low as 500 kg ha^{-1} have been realized in some parts of Western Kenya (Otingah *et al.*, 2007). The potential maize yield in Western Kenya is 4-5-ton tons ha^{-1} according to Vanlauwe *et al.*, (2008). Woomer & Savala, (2009) reported that *Striga* parasite was infecting about 217,000 ha in Kenya, causing annual crop loss of Ksh 5.3 billion.About 1000 *Striga* parasites per hectare as the ability to cause a grain yield loss of 2-3 kg ha^{-1} of sorghum (Atera *et al*,.2012). However, this loss can be higher on maize. Despite the efforts to develop resistant varieties,it has not been possible due to adaptivity and existenceof various physiological strains of *Striga* parasite and thus this calls for more than one strategy to control. Of the 23 *Striga* species in Africa, *Striga hermonthica* infest about 40% of arable land in East Africa, (Khan *et al.*, 2002, Gressel *et al.*, 2004). An integrated approach that targets the development stage and depletion of the seed bank is ideal. The most effective control methods are chemicals, but they are expensive and cannot be afforded by many small-scale farmers. Furthermore, chemicals cause environmental concerns. Food production to feed the growing human population has to be achieved without accelerating environmental degradation from excessive chemical use.

Crops like amaranth provide farmers with the option to increase the diversity of crops grown. Increasing the diversity of crops reduces the risk of insect, disease and weed pests becoming serious problems. A diverse cropping enterprise also helps insulate a farmer from the price vagaries of a single commodity market.

1.3 Justification

The world's total demand for food is likely to nearly double its present level by 2030, and there is limited new land available for expansion of cultivation to achieve this production level. *Striga* weed is reported to infest an estimated area of 44 million hectares worldwide (Mignouna *et al*., 2013). More than 21% of the total maize area in East Africa is infested by *Striga* (Parker, 2009). Kanampiu, (2002) reported that 76% of maize and sorghum cropping areas in Kenya are infested by *Striga*. Buckler and Stevens, (2006) gave an explanation that maize is not native to Africa hence its resistance against the weed is poor.

Research conducted over several years in Africa has come up with several technologies for *Striga* control which include the use of resistant and tolerant varieties, and various agronomic practices, herbicides, fertilizer and manures

(Esilaba, 2006). The Imazapyr - resistant maize (IRM) technology, though introduced on a large scale in 2004 only 28% of the sampled households in Western Kenya adopted it and the reasons for this low adoption were unclear (Odendo *et al.,* 2001). However, Khan (2006) found out that the reason behind non adoption was due to mismatch between technologies and farmer's socio-economic conditions,considering that most farmers in the region are small scale poor resource farmers.

The use of herbicides is becoming more and more limited, due to changes in environmental concerns. Herbicides such as Dicamba®, as 2, 4-D, bromoxymil®, imidazolinone, imazapyr® that inhibit aceto lactate synthase (ALS) have been used in Kenya especially on imidazoline-resistant (IR) maize (Kanampiu *et al*., 2002).

The use of herbicides also can lead to restrictions on subsequent rotational crops, export restrictions due to strict regulations contamination among other concerns. Moreover, the use of chemicals to control weeds is a short-term strategy.

Currently,more emphasis is on integrated pest management (IPM) system with the aim of reducingchemical usage thus reducing adverse environmental impacts.

Striga infestation is mostly a problem affecting the resource-poor farmer. It is most problematic on soils that are intensively cultivated and depleted of key nutrients and organic matter. Most of the harvested parts of plant cereals and legume are not returned to the fields, hence causing soil mining.

The complexity of *Striga* weed means that long-term research efforts should be aimed at reduces the *Striga* seed bank in the soil. One of the tested methods of *Striga* control considered being more viable, cost-effective and practical to small-scale farmers is the use of trap crops (Omanya *et al.*, 2004). Trap crops have root exudates that stimulate *Striga* plants to germinate but the weed cannot parasitize them and eventually die reducing the weed's seed bank and infestation. According to Schultz, (2003), annual double cropping of trap crops reduced the seed bank by about 30%.

Examples of trap crops of *S. hermonthica* are cotton, soybean, groundnuts, *Hypisspicigera* and cowpea which induce suicidal germination. Schultz *et al.,* (2003) achieved 50% seed bank reduction after one year's rotation with soybean and cowpea under farmer-managed condition. Carsky *et al*., (2002) compared the *Striga* incidence in maize after soybean with that of maize after sorghum and reported that it was significantly reduced from 3.2 to 1.3 emerged plants per maize plant and resulted in improved grain yield. Reduction of *Striga* emergence by inhibiting radicle growth, hence no attachment, increase in soil fertility and smothering effects have been suggested as mechanisms behind the legume reduction of *Striga* effect (Khan *et al*., 2002).

Although potentially the most valuable trap crops in *Striga* control are legumes (Berner, 1997), there is variability in stimulant production among crop species and cultivars. The use of legume intercrops is still low due to lack of awareness among the farmers, lack of legume's seedlings and competition for space with other food crops. High stimulant crops still need to be identified and used in controlling *Striga*. The most efficient method of selecting trap crop cultivars is to initially screen for stimulant production in the laboratory, followed by field screening.

Laboratory screening of *Amaranthus* lines at growth stages for suicidal germination of *Striga* seeds showed that *Amaranthus* lines can induce suicidal germination of *Striga* seeds and could be used as a trap crop to control *Striga* weeds (Alabi, 2007). Grain amaranth has the potential to substitute expensive animal protein because of its comparable protein quality and quantity. Despite its nutritional qualities, its production and consumption are still limited in Kenya. Limited information is however available about the relative efficacy of the accessions and varieties to cause germination of *S. Hermontica* seeds and prevent parasitism. “Trap” crops are effective and can be used to reduce soil seed banks and stimulate the suicidal early germination of *Striga* spp. seeds in a rotational strategy. Several studies have shown a significant reduction in *Striga* attack by adopting cropping systems that include intercropping and rotations (Carsky *et al.*, 2002; Schultz *et al.*, 2003). Crop rotation significantly influences N use efficiency and prompts changes in various N sources, affecting the availabilityof the plant (Lopez-Bellido, 2001).

Grain amaranth is still an underexploited plant in Kenya despite it's unique nutritional and promising economic value due to the variety of uses and benefits to producers, processors and consumers (Muyonga *et al*., 2008). It has also been observed that where grain amaranth has been grown by some farmers, *Striga* population reduces. However, the limited information is available about the relative efficacy of its accessions and to cause germination of *S. hermonthica*seeds and prevent parasitism.

Therefore, there was a need to evaluate grain amaranth’s ability to cause suicidal germination of *Striga*. Its nutritional value is very high in comparison to other food crops (table 1) and can also be used by people with special nutritional needs e.g. person diabetes, high blood pressure and HIV infected. Grain amaranth has been reported to increases physical strength, and as a substitute for milk, particularly during child-weaning.

The table below shows the nutritional components of grain amaranth and other common food crops.

Table 1: Nutritional components of grain amaranth and other common food crops

Crop	Grain amaranth	Wheat	Rice	Sweet corn	Potato
Component (per 100g portion)	Amount	Amount	Amount	Amount	Amount
water (g)	11	13	12	76	82
energy (kJ)	1554	1368	1527	360	288
energy (kCal)	371	327	365	86	69
protein (g)	14	13	7	3	1.7
fat (g)	7	2	1	1	0.1
carbohydrates (g)	65	71	79	19	16
fiber (g)	7	12	1	3	2.4
sugars (g)	1.7	<0.1	>0.1	3	1.2
iron (mg)	7.6	3	0.8	0.5	0.5
manganese (mg)	3.4	4	1.1	0.2	0.1
calcium (mg)	159	29	28	2	9
magnesium (mg)	248	126	25	37	21
phosphorus (mg)	557	288	115	89	62
potassium (mg)	508	363	115	270	407
zinc (mg)	2.9	2.6	1.1	0.5	0.3
vitB6 (mg)	0.6	0.3	0.2	0.1	0.2

Source;https://www.agriculturejournals.cz/publicFiles/53035.

Grain amaranth established faster and covers the ground outcompeting weeds such as *Striga*. The crop is currently being promoted as an important source of protein among the poor. Grain amaranth was gazetted in Kenya in legal Notice No.281 of 19thJuly 1991 as a food crop. The poverty eradication commission in Kenya launched a projection in 2005 to promote the cultivation of grain amaranth as a food security crop in districts where traditional crops often fail due to drought associated with climate change. *Striga* weed undermines the struggle to attain food security and so its control must be addressed by all means. Large areas of land are infested with *Striga* and hence there was a need to identify more trap crops in order to provide farmers with the wider selection so that they can choose that suit their Agro-ecological zones.

Thus, this study was done in Siaya County by rotating maize at different rates of N fertilizer with grain amaranth and soybeans. Grain amaranth was easy to establish, and its seeds could be obtained cheaply.

1.4 Research objectives

1.4.1 Broad objective

The main objective was to determine the rotational effects of grain amaranth, soybean, and nitrogen fertilization on *Striga* infestation and maize performance "targeting small-scale farmers in Siaya County of western Kenya".

1.4.2 Specific objectives

Specific objectives were;

1. To evaluate the effect of rotating grain amaranth and soybean with maize and its interactions with nitrogen on *Striga* infestation.
2. To evaluate the effect of grain amaranth, soybean and nitrogen fertilizer rates on maize yield and yield components in *Striga* infested soils.
3. To assess the economic benefits of including grain amaranth and soybean in crop rotation on the management of *Striga* weed in Siaya County.

1.5 Hypothesis

Ho: Crop rotation of grain amaranth-maize, soybean-maize,maize-maize and rates of nitrogen will have no significant differential effects on the intensity of *Striga* weeds.

Ho: Crop rotation of grain amaranth-maize, soybean-maize,maize-maize and rates of nitrogen will have no significant difference affects yield and yield components of maize on *Striga* infested soils.

Ho: grain amaranth will have no effect on Striga intensity.

Ho: Grain amaranth and soybean have similar economic benefit when included in crop rotation during the management of Striga weeds.

1.6 The significance of the study

This study will contribute to providing useful information on grain amaranth as an alternative crop in *Striga* weed control, one of the underutilized most nutritious crops in the world. It will provide information on a crop rotation system and N rates that will guide smallholder farmers on the management of grain amaranth and soybean crop in the region. Lastly, the study will bring useful information which can guide extension services on better management practices of maize-amaranth and maize-soybean cropping system to be recommended to the smallholder farmers of western Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Grain amaranth (Amaranthus hypochondriacus L.)

2.1.1 Origin and distribution

Grain amaranth is one of the oldest crops cultivated in Africa, the Caribbean, Asia, America and Asia (Gigliola, 2012).It is believed that amaranth originated in Central and South America because it was a staple crop of the ancient Aztec and Inca civilizations and it is distributed worldwide in warm, humid regions ("Amaranth," 2015). O"Brien& Price, (2008) reported that grain amaranth was domesticated as early as 6000 years ago in Central America and the vegetable amaranth has been used in China for over 400 years. The crop is said to have been grown along with maize and beans, as an integral part of their cropping systems.

Grain amaranth has been successfully grown in many different countries with contrasting environmental conditions. These include Australia, Argentina, South Germany, Poland China, Sweden, Hungary, Chile, Guatemala, Mexico, Thailand, India (Saunders and Becker, 1984), and Kenya (Gupta and Themba, 1992). Andreas *et al.,* (2011), referred amaranth has as drought-tolerant crop could be the reason why it has the ability to grow under a wide range of climatic condition.

2.1.2 Botany

Grain amaranth, genus (*Amaranthus*) consists of 60–70 species of flowering plants in the family Amaranthaceae. A few amaranth species are useful as food crops and are grown both for their leaves and for their edible seeds, which are a nutritious pseudo cereal. However, most species are weeds. Amaranthus uses the C4-cycle photosynthetic pathway. This enables it to be very efficient in sunlight and nutrients utilizing at high temperatures (O‟Brien& Price, 2008). This characteristic also enables amaranth to require less water common in C3 carbon-fixation pathway of plants. Common grain amaranth domesticated are; *A. hypochondriacus* (prince's feather), A. cruentus (purple amaranth) and *A. caudatus* (love-lies-bleeding) (Yarger, 2008). The three can be differentiated by their variation in physical appearance and characteristics. Amaranth seeds are quite small and range from 0.7 to 0.9 g per 1000 seeds, often leading to the poor and non-uniform seedling establishment (Brenner *et al.,* 2000).

Other than grain and leaf crop, amaranth species have been cultivated in the Old and New World since ancient times as, pot herbs, ornamentals, and dye plants (Venskutonis & Kraujalis, 2013). The red dye from amaranth leaves is used to colour alcoholic beverages in Bolivia and northwestern Argentina, to colour maize dough in Mexico and the southwestern United States and to dye foods and beverages in Ecuador (Sauer, 1950).

Due to its nutritional importance, there has been great interest in grain amaranth farming in the international community. In Kenya, most government and non-government organizations are involved in the promotion of the crop.

2.1.3 Agronomy

Grain amaranth is established by means of seeds. The seedbed needs to be prepared to fine tilt due to the small size of the seeds. The furrows are then prepared 10 cm apart and 0.5-1 cm deep. To ease sowing, seeds are mixed with sand at the ratio of 1g of seed to 100g of sand. Seeds are sown 5 cm apart within the row. The seeds are then covered lightly with a layer of compost or rice hulls (Shukla *et al.*, 2010). Alternatively, the seeds can be directly broadcasted uniformly at the rate of 0.5 to 1.0 g/m^2 of bed.

Recommendations for the optimal crop density for grain amaranth spacing is 4-47 plants/m^2. However,the optimum density depends on the site and variety (Shukla *et al.,* 2010). High density may lower the grain yield as well as grain mineral composition. However, this may depend on other factors like soil conditions, weather, management and grain amaranth variety. Likewise, density trials on other crops such as sorghum suggest that plant population might affect the grain components of amaranth. The highest amaranth grain yields are achieved at the lowest populations. A kilogram of grain seed is enough for one acre (about 2 million seeds), (Mugisha, 2012).

Amaranth grows from sea level to 2400 m altitude. Normally the hotter it is the better it grows, and it generally thrives within a temperature range of 22-30°C. A minimum temperature of 15 to17°C is needed for seed germination and for optimal growth. Amaranth is grown during both wet and dry seasons, though irrigation is normally required for dry season crops since the rate of transpiration by the leaves is fairly high, (Brenner *et al.,* 2000). Although *Amaranthus* is known to be a relatively drought-resistant crop, insufficient water reduces yield (Andreas *et al.,* 2011). Its water requirement is reported to be 42-47 % that of wheat, 51-62 % that of maize and 79 % that of cotton (Mwangi, 2003) and therefore survives better than most crops under dry and hot conditions because of its extensive root system.

Amaranth grows in a wide range of soils as long as the soil has good water holding capacity and pH range from 4.5 to 8.0. However, the crop does well in loam or silt-loam. Amaranth grows poorly on compacted soils. Therefore, if the soils are compacted, ploughing down green manure prior to planting amaranth will be of great importance (Andreas *et al.,* 2011).

Though grain amaranth grows in soils of low fertility, the use of organic and inorganic fertilizers has been reported to increase both leaf and grain yield. Onyango *et al.,* (2012), reported that, although amaranths are known to perform well in poor soils, they also respond positively to nitrogen (N) fertilization. Manga (2001) reported that application of nitrogen at the rate of 50 kg ha-^{1} significantly increased the vegetative growth and development of *Amaranthus cruentus* through increased plant height, plant dry matter weight and leaf area index.

Grain amaranth has been shown to respond well to organic sources of N (Makinde, 2015). Organic fertilization strategies also limit nitrate accumulation (Onyango *et al.,* 2012). Thus, this positive relationship between N fertilization and amaranth yield should be maximized by farmers, taking advantage of amaranth’s low fertility requirements to prevent nitrate accumulation, nutrient leaching, and expenditure on purchasing fertilizers. Nyankanga *et al.,* (2012) recommended the use of 9 t ha-^{1} cow dung manure western Kenya to obtain maximum grain yield.

Kenyan farmers in regions with marginal rainfall plant amaranth rather than maize because they believe there is less risk of crop failure with amaranth. Grain amaranth can be intercropped with other cereals, legumes and various vegetables (Ng’ang'a*et al*., 2008). Amaranth takes between 45 and 75 days to mature, depending on the variety and the weather. It is one of the fastest maturing grains in the world.

2.1.4 Yield

Amaranth seed can yield up to 3 tons/ hectare when grown in monoculture for 3-4 months, and a vegetable yield of 4.5 tons of dry matter/hectare, an acre if the farmer observes all the crop management programs, (Grubben & Denton 2008). Recovered yields in farmers' fields have ranged from 100 kg ha-^{1} to as high as 1500 kg/ha. Hand-harvested yields have been as high as 4000 kg ha-^{1} in Montana (Cramer 1988) and

6000 kg ha-^{1} in Peru (Sumar *et al.*, 1986) and hand-harvested yields ranged from 2200 to 3000 kg/ha in western Kenya (*Nyankanga et al.*, 2012). Research has shown that it produces even higher than this if better crop husbandry is put in place. Amaranth has got very high productivity, coupled with the ability to withstand harsh weather. The market is open for this crop. It can be sold both locally and internationally. According to Ngugi *et al.*, 2006, grain amaranth production can be a viable tool for poverty reduction for women with little capital, limited access to land and work under labour constraints.

Surveys indicated that 21% of the population in Uganda had already grown grain amaranth during 2006, while by 2007 the percentage had jumped to 76% (Sseguya, 2007). According to a survey conducted by VEDCO 2007, amaranth was grown by diverse groups of people, notably among people with special nutrition need such as HIV/AIDS patients.

2.1.5 Pest and diseases

Amaranth is susceptible to damage by foliar insects such as leaf miners, leaf roller caterpillars (*Tetranychus* spp.), cutworms, aphids, flea beetles, stem weevils, spider mites and stem borers. Tarnished leaf bug (*Lyguslineolaris* P. Beauv.) is considered the greatest pest of amaranth globally, damaging plants through its sucking action on meristematic tissue and developing floral buds, blossoms and embryos (Ebert *et al.,* 2011).

An effective method of controlling insect pests is to cover the bed with a fine screen or nylon mesh netting (32-mesh or finer).

Grain amaranth has no major disease problems. However, some of the diseases that attack the crop are fungal and include damping-off (caused by *Pythium* *aphanidermalum* and *Rhizoctonia solani)* and Choenephora blight caused by *Choenephora cucurbitarium* (Yongo, 2009). Damping-off is favoured by high soil moisture, low soil temperature and high plant density. Seeds affected by damping-off may rot in the soil before the emergence.

Generally, amaranths are known to be resilient to herbivore attacks and resistant to bacterial and fungal wilt (Achigan-Dako *et al.,* 2014).

2.1.6 Utilization of grain amaranth

Currently, amaranth is called the third-millennium plant because of its high nutritional value and undemanding cultivation. Amaranth is one of those rare plants whose leaves are eaten as a vegetable while the seeds are used as cereals (Saunders and Becker, 1984).

The vegetable has shown up in increasing quantities in the formal markets, where the middle and higher socio-economic classes shop (Ngugi *et al*., 2006).

The grain is also used in fortified food where the staple food is low in certain elements. It contains 15 to 18% protein, which is higher than most grains except soybeans. The grains are high in essential amino acids, e.g. 0.85% lysine (Rastogi & Shukla, 2013). Amaranth has high fibre content (7%), which is more than in wheat, barley, rye, rice and maize (Mustafa *et al.*, (2012), which has the beneficial role of dietary in human nutrition.

Grain amaranth has been found to have medicinal values and has been used in the management of diabetes, migraines, hypertension, liver disease, haemorrhage, TB. HIV/AIDS, wounds, kwashiorkor, marasmus, stunting, diarrhoea and skin diseases. It also contains dietary fibres important in the prevention of coronary heart disease and cancer of the colon. Consumption of the grain has been known to enhance human growth and development, improve general health and strengthen body immunity (Wambugu & Muthamia, 2009). Amaranth appears to lower cholesterol via its content of plant stanols and squalene. It also has calcium, iron, potassium, phosphorus, vitamins A, C and E (Kim *et al.*, 2006). Due to this grain amaranth is believed by many to be the most nutritious grain on earth.

Species of the Amaranthus genus are also used as ornamental plants because of their intensive inflorescence colour (Brenner *et al,* 2010).

Grain amaranth provides farmers with the option to increase the diversity of thus reducing the risk of insect, disease and weeds and price fluctuations.

2.2 *Striga* weed

2.2.1 *Striga* weeds origin and distribution

Kamanga (2013) stated that *Striga hermonthica* originated in Nubian mountains of Sudan and parts of Ethiopia.The weed problem has been in existence as early as 1936 in the fields of farmers within Lake Victoria Basin western Kenya (Khan *et al*., 2006). It is also widespread in eastern and northern Uganda on sorghum and finger millet (Dogget, 1965). Crop losses also occur widely in parts of the Gambia, Senegal, Mauritania, Togo, Ghana, Kenya, Tanzania, Uganda, Botswana, Swaziland and Mozambique and more locally elsewhere in Africa, Asia, Australia and the USA (Mahmoud, 2013).

Abdul (2012) reported that *Striga asiatica* is common in coast province where upland rice is grown. Losses due to *Striga* depend on striga density, host species and genotype, land system, soil nutritional status and rain pattern (Atera *et al*., 2012). Poor farming methods among farmers have led to the depletion of soil fertility which is the main cause for the increase in *Striga* incident.

The relatedness of species is commonly assessed by morphological characters. However, the reliable closeness of parental species has been evaluated according to the level of successful hybridization and fertility of the resultant progeny (Aigbokhan *et al.,* 2000). Based on their morphological similarities, it has been suggested that *Striga*s species have formed complex groups (Aigbokhan *et al.,* 2000). Some of these species such as *S. hermonthica* and *S. Aspera*are found in the same locality, parasitizing the same cereal crops and wild grasses, sharing insect pollinators and can be intercrossed to produce seeds. Mohamed *et al*., (2007) proposed that there are several factors that have contributed to genetic diversity in *Striga*: (a) persistent seed bank of several generations of populations; (b) hybridization; (c) broad geographic distribution; (d) long-distance dispersal and (e) locally adapted host races. Among these factors, geographical distribution appears to play the greatest role in determining genetic differences in the species (Aigbokhan *et al*., 2000). *Striga* seeds are dispersed by wind, water, soil movement, human activities or by adhering to the feet, fur or feathers of animals.

It is estimated that one *Striga* plant can produce approximately 4,827 seeds in a mature capsule. There are about 61 to 158 million *S. hermonthica*seeds per hectare of land (Khan *et al*., 2006; Vanlauwe *et al.,* 2008). *Striga hermonthica* seeds are very small (0.2 × 0.3 mm), lightweight (0.4–0.5 × 10–2 mg), (Parker & Riches, 1993). According to Woomer and Savala (2009), weed produces 1,881 seeds. A survey conducted in the savannah zone of Ghana showed that an average number of 9,384 seeds m^2 was found in the Land that had been returned to cultivation after fallow. However, some fields had seeds in excess of 14,900 seeds m^2 (Abunyewa & Padi, 2003).

Studies show that there are 14 *Striga* weeds per m^2 in western Kenya (McOpiyo *et al*., 2010), hence cereal production is unsustainable in the region. The *Striga* incident in maize is increasing in the most transitional zones in Kenya with a total affected area of about 300,000-500,000 ha (Atera, 2012).

The map below shows the distribution of *Striga hermonthica* in parts of western Kenya.

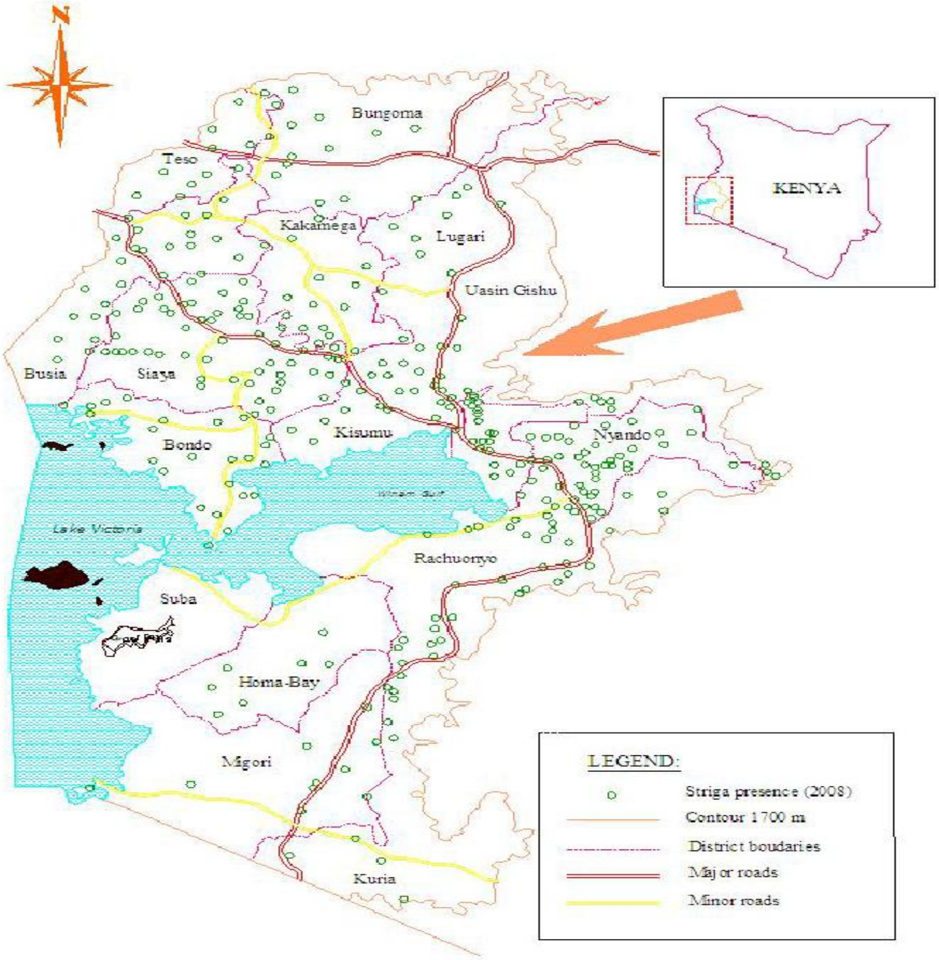


Fig 2: Map showing the distribution of strigahermonthica in parts of western Kenya (De Groote *et al.*, 2008).

2.2.2 Economic effects of *Striga* weeds

Young *Striga* seedlings are completely parasitic on the host while they are below the soil level and, at this stage, cause maximum damage to the host. The weed causes direct loss of water, minerals, nitrogen and carbohydrate leading to stunting of the plant. The weed has the ability to change the host plant architecture and reduce the water-use efficiency in the host (Mignouna *et al*., 2013).

Striga infestation causes a loss of 30-50% to Africa's agricultural economy on 40% of its arable land (Amudavi *et al*., 2007; Hearne, 2009). *Striga* infests an estimated two-thirds of 73 million hectares under cereal crops in Africa resulting in crop losses of up to 70% among the subsistence farmers (Kanampiu *et al.*, 2002). A survey conducted in 30 communities in Borno state, northern Nigeria, indicated that farmers rated *Striga i*nfestation as the leading priority constraint together with low soil fertility to crop production (Dugje *et al*., 2006). Similar surveys (Kim *et al*., 2006) showed *S. hermonthica*is a serious problem in Guinea savannah of Nigeria and yield losses ranged from 10 to 100%. In western Kenya, a survey of 83 farms revealed that 73% of the farms are infected with*S. Hermonthica* (Woomer & Savala, 2009). An estimate of 75,000 ha of land (80% of farmland) is infested with *Striga*. The average yield loss due to Striga is 1.15, 1.10 and 0.99 tons per hectare for maize, sorghum and millet, respectively (McOpiyo *et al*., 2010). However, the damage can reach as high as 2.8 tons per ha in maize and sorghum in some locations with high *Striga* densities (Andersson &Halvarsson, 2011). The loss of represents 12.3% of the 2.4 million metric tons of maize that Kenya produces annually. This translates to about 39.6 kg of maize loss per capita, amounting to about 20% of a typical person's annual food requirement. Clearly, this show then the consequences of *Striga* infections is severe rendering small-scale farmers helpless and often bewildered. In addition to the yield reduction, *Striga* also causes abandoning of arable fields by farmers, which result in food insecurity and malnutrition (Gressel, 2004).

2.2.3. Efforts to control *Striga*

High reproductive rate and seed longevity of the *Striga* parasite, combined with a complicated mode of parasitism that occurs underground has complicated the control of *Striga* weed (Midega *et al.*, 2014). Research, however, has shown that integrated weed management systems have the potential to reduce herbicide use (associated costs) and to improve weed suppression over the long term. Hand-weeding is the most widely practised control method for *Striga* in Kenya. Due to high labour costs in repeated hand-pulling of *Striga,* it is recommended that hand-pulling should not begin until 2-3 weeks after *S. hermonthica* begins to flower to prevent seeding (Parker and Riches, 1993). Hand-pulling will usually need to be continued for 3-4 years and is most economical on the least infested fields (Parker and Riches, 1993).

Generally, *Striga* control can be possible and sustainable if a wide range of individual technologies is combined into a program of integrated *Striga* control (ISC) to serve a range of biophysical and socio-economic environments. Reduced soil fertility is conducive for *Striga* to build to levels that prevent the production of cereals (Berner *et al*, 1997).

Traditional farming systems in Africa include crops that are more tolerant of *Striga*. Host plant resistance is an effective means to reduce the reproduction of the parasite. The main success using this approach has been on sorghum in East and Central Africa (Midega *et al.*, 2014).

There are conflicting reports on the effect of intercropping cereals (hosts) with legumes (non-hosts of cereal *Striga*). Intercropping grain with legumes is a practice that requires more information before widespread adoption of the technology. Grain legumes help maintain and improve soil fertility due to their ability to biologically fix atmospheric nitrogen. However, studies in Kenya indicate that intercropping with cowpeas between the rows of maize significantly reduced *Striga* numbers when compared to within the maize rows (Odhiambo and Ransom, 1993). On-farm trials show that intercropping of maize and beans in the same hole in *Striga* infested farmers' fields increased maize yields by 78.6%in western Kenya (Odhiambo and Ariga, 2004). Similarly, *Desmodium uncinatum* and *D. intortum* intercropped with maize to repel stem borers reduced *Striga* infestation in western Kenya (Khan *et al.*, 2002).

Crop rotation with non-host crops has been reported to disrupt the production of *Striga* that leads to a reduction of the weeds. Crop rotation is a low-cost technology that can be used to addresses the problem of low soil fertility and *Striga* infestation especially when legumes are involved, and also more fallow included in the crop rotation (Khan *et al*., 2002). Crop rotation involving soybean and maize was more effective in reducing *Striga* infestation and also gave higher maize grain yield than cowpea in Guinea savanna of Nigeria (Yusuf & Iwuafor, 2009).

2.3 Nitrogen

Nitrogen is the major nutrient added to increase crop yield, and it is known also to affect crop–weed competitive interactions. Nitrogen fertilizer can affect weed germination and establishment. The nutrient is needed during the first weeks of legume establishment as it helps in the formation of source leaf which is important for photosynthesis. Many weeds are high-N consumers, thus their establishment in fields limits N for crop growth. Weeds not only reduce the amount of N available to crops, but the growth of many weed species also is enhanced by higher soil N levels (Blackshaw *et al*., 2003).

The use of nitrogen to suppress *Striga* has been demonstrated in the East and Central African highlands (Gacheru & Rao, 2001).

The suppressive effects of N on *Striga* infestation were attributed to delayed germination; reduced radical elongation reduced stimulants production and reduction of seeds response to the stimulants. Host plant resistance would probably be the most feasible and potential method for parasitic weed control (Omanya, 2001).

Nitrogenous fertilizers combined with phosphorous and lime has been reported to increase maize yield from 0.2 MT ha-^{1} (control) to 3.0 MT ha-^{1} in the acidic soil of western Kenya (Mbakaya *et al*., 2006). Increasing N and maintaining levels of P and K applications will directly cause a decrease in *Striga* density (Kamanga, 2013).

Delaying N applications, applying slow-release N fertilizers, or placing N below the weed seed germination zone could be potential strategies for reducing early season weed establishment in integrated cropping systems (Kamanga, 2013).

Green manure (good source of N) and N fertilizer enabled the host to avoid the effect of *Striga* probably by the poor production of germination stimulants and delayed haustoria attachment. In addition, under good supply of N host grow vigorously and creates an unfavourable environment for *Striga* germination and development hence short *Striga* plants.

Nitrogen is essential for plant growth and it is still one of the major factors limiting crop yield. Nitrogen becomes available to plant only after it has entered the soil solution as nitrate (NO^{-3}) or ammonium (NH_4^+) ions through the microbially mitigated processes of mineralization and immobilization, respectively. It is the most limiting nutrient for crop production in many parts of the world’s agricultural areas and its effective use is important for the economic sustainability of cropping system (Fageria and Baligar, 2005).

Esilaba (2006) found that although *Striga* infection generally declined with increasing N availability, the impact was partially dependent on the severity of infestation. The inadequacy of N fertilizer reduces the congregation of dry matter and leads to growth reduction.

2.4 Maize

Maize origin can be traced to tropics of Central America sub-continent where it is believed to have been domesticated from the wild Teosinte *Zea Mexicana* (Bonavia, 2013). Maize is grown across a wide range of agro-ecological zones, (Lelei *et al*., 2009). The crop can be grown in a wide range of soil which includes; vertisols, andosols, phaenozems, luvisols, cambisols, acrisols, nitisols and ferralsols (Muchena *et al*., 1998, Jaezold and Schmidst, 1982). It does well in temperatures of 15 to 22^{0}C and altitude of 1000 to 2900m above the sea level.

Maize (*Zea mays L.*) is one of the most important food crops in the world, together with rice and wheat, provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries (FAOSTAT, 2010). Maize is produced on nearly 100 million hectares in 125 developing countries (FAOSTAT, 2010). In parts of Africa, maize alone contributes over 20% of food calories.

In Kenya, maize is a staple food for both rural and urban populations as well as feed for livestock. It is composed of approximately 76-88% of carbohydrate, 6-16% of protein, 4-5% fat and 1.3 of minerals. Maize is Kenya's most important crop. The 2011-13 FAOSTAT report indicates that more than 2.1 million ha of Kenya's 5.3

million ha of all crops harvested area was occupied by maize. The translation of this is that maize accounts for 40% of all crop area in Kenya.

Despite its high demand globally, maize production has been low and this is attributed to many factors like the decline of soil fertility, poor agronomic practices, and limited use of inputs, insufficient technology generation, poor quality seeds, diseases and weeds (Woldesenbet *et al.*, 2016).

A major problem for maize farmers in western Kenya is the increased population of *Striga* weed. The weed causes severe losses and has a major economic impact on small-scale holders (Vanlauwe *et al*., 2003). In western Kenya for instance, maize *(Zea mays L)*, which is the staple food, farmer production yields average at less than 1ton ha^{-1} (Opala *et al.*, 2015). Traditional farming systems in Africa include grains that are more tolerant of *Striga* and more fallow in crop rotation (Khan *et al.*, 2002). However,fallowing is almost not possible due to population pressure.

2.5 Soybean

The soybean belongs to the family Leguminosae, subfamily Papilionoideae, and genus Glycine, L. Soybean (*Glycine max* (L.) Merr.) is recognized as one of the oldest crop species cultivated by man.

2.5.1Soybean production

The crop can be successfully grown in many agro-ecological zones using low agricultural input (Beutler *et al.,* 2014). However, soybean plant grows well at pH levels between 6.0 and 7.0, with the optimum value of 6.3 to 6.5 (Staton, 2012). The production of soybean in Kenya is still and is estimated at 8,000 mt /yr. The low soybean grain yields experienced in these soils could be attributed to declining soil fertility (Thuita *et al*., 2012). Western Kenya is the major producer, supplying 80% of the total of soybean in Kenya. The crop is mainly grown by smallholder farmers (0.1 to 0.2 ha) (Mahasi *et al.,* 2011). Also, it has been found to be agronomically compatible with other common arable crops.

2.5.2 Utilization of soybean

Soybean is one of the legume crops with high protein content, source of cooking oil and important in soil fertility enhancement. Being a legume, including soybean in crop rotations is very important for buffering yields in case of climate variability and maintaining N balances during low rainfall season (Tully *et al.*, 2015). Soybean has been reported to induce abortive germination of *Striga* seeds, with a consequent reduction in an infestation. Soybean can positively contribute to soil health, human nutrition and health, livestock nutrition, household income, poverty reduction and overall improvements in livelihoods and ecosystem services than many others leguminous grain crops. It is rich in protein, unsaturated fatty acids, Ca and P minerals and vitamins A, B, C and D. Soybean's seeds also contain 42-45 % best quality protein and 20-22 % edible oil compared to other legumes which contain merely about 20 % proteins (Mauyo *et al.,* 2010).

Preliminary research has identified soybean as a potential trap crop because of its ability to induce suicidal germination of *Striga* and improve soil fertility. When rotated with cereals it can contribute to yield increases of cereals by up to 25% (Sanginga *et al.,* 2003; Mahasi *et al*., 2011). This is because of its ability to fix up to 200 kg N ha-1 years under optimal field conditions (Cheminingwa *et al*., 2007).

2.6 Economic cost analysis

This was done using CIMMYT 1988.Pooled results from the three sites for maize, grain amaranth and soybean yield were averaged for analysis. This was then adjusted down to 10% because of the difference between experimental data and yields under farmer-managed conditions (CIMMYT 1988). The analysis was done using a partial budget for the experiment. Net returns were then calculated. The cost of production and returns were calculated using the prevailing market prices of both inputs and outputs. The economic analysis provides a foundation for comparing the profitability of alternative treatments and how robust profits are in the event of changing product or input prices. This is the information used to make recommendations to the farmers.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of study and farmer selection

The experiments were set up in farmers' fields as an on-farm trial in Ugunja, Siaya County among three farmers 'namely Asango, Jacob and Evalyne where *Striga* weed was a serious problem.

Siaya county, formerly Siaya district lies between latitude 0^0 $03^{'}$N and latitude 34^0 $25^{'}$ E. The altitude ranges from 1140 to 1400 M above the sea level. Temperature varies from 27^0C to 30^0C and 15^0C to 17^0C maximum and minimum ranges respectively. Soils are mainly from volcanic origin, mainly basalt, well developed, deep and friable but shallow, with murram in some places. Common soil type is dystric nitisols, orthicferralsols and acrisols (FAO, 1996 and the Republic of Kenya, 1994). The County receives bimodal rain with long rains March-June and short rains in August-November (Mutuo *et al.*, 2007). Main economic activities in the area are farming and fishing.

Sites selected were well-drained, levelled fields, uniform infertility and soil type with no termites and soil erosion. Site characterization was conducted to determine the present physical and chemical properties of the soils.

Pre-visit to the area was done during the previous cropping season and the farmers were selected based on the availability of *Striga* infested plot, willingness to grow the crop combinations, availability of labour to carry out treatment operations in time and as required, as well as allowing access of experimental farm to other interested farmers.

3.2 Experimental design and treatments

The experimental plots were ploughed and ridged at an inter-row distance of 0.75metres. Each plot size measured 17 x 4 m. In the first season of August-December in 2014, maize (KSTP 94 variety), grain amaranth (golden variety), and soybean (TGX 1740-2F (SB19) variety) were planted as the main crops. In the second season of rotation of February-August 2015, the experimental design was a split-plot and only maize was planted on all plots. The main plots were the previous grain amaranth, soybean and maize while the subplots (4 x 3 m) were five levels of N fertilizer i.e. 0, 50,100,150 and 200 kg N ha^{-1} giving a total of 15 treatments. The nitrogen was applied during using split application system.

The treatments were as shown in Table 3below

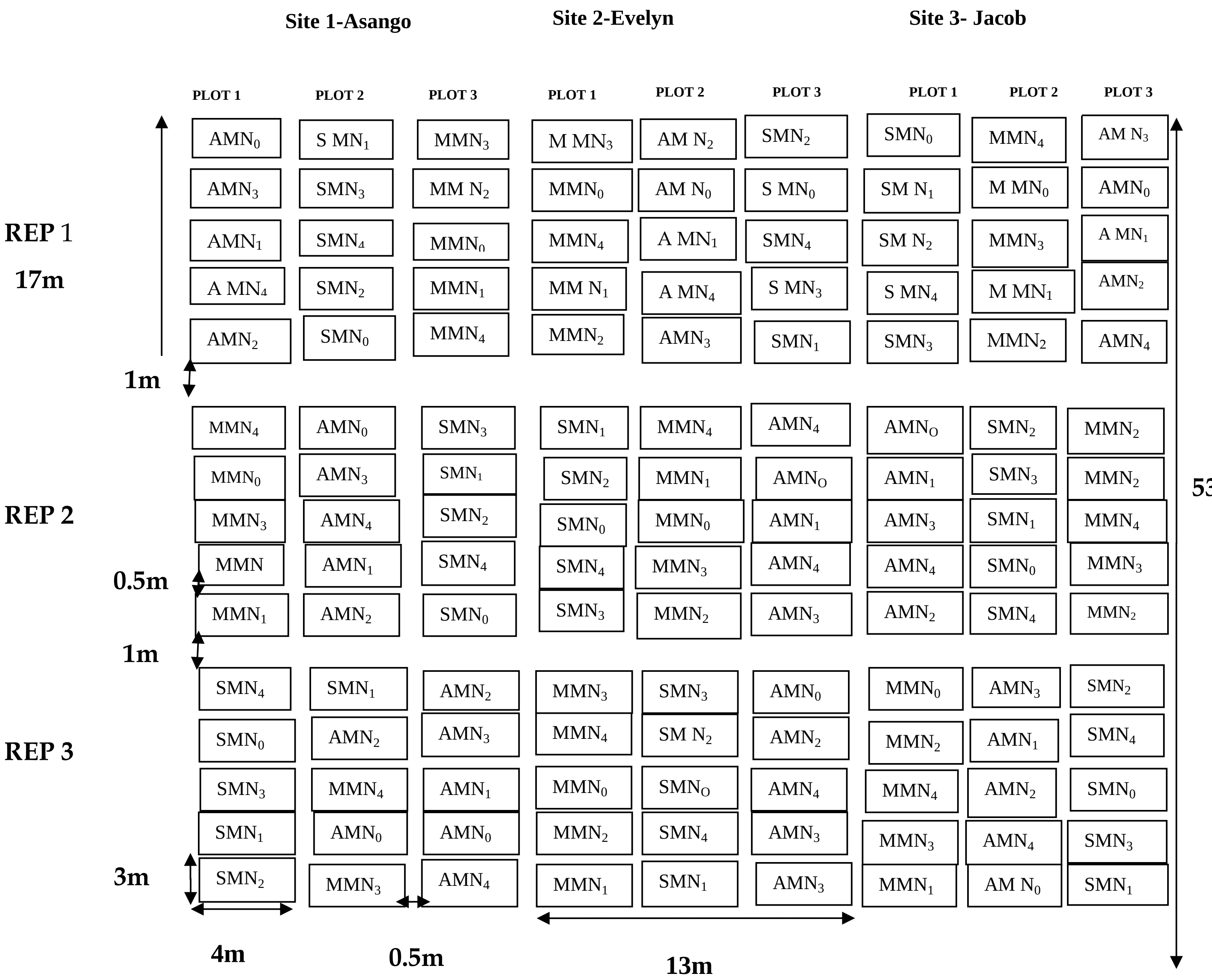
Table 2. Treatment structure adapted for the study.

Code	**Description**	**N rates (Kg/ha)**
AM N_0	One season Amaranth followed by one season of maize	0
A MN_1	One season of Amaranth followed by one season of maize	50
AMN_2	One season of Amaranth followed by one season of maize	100
AM N_3	One season of Amaranth followed by one season of maize	150
A MN_4	One season of Amaranth followed by one season of maize	200
SMN_0	One season of soybean followed by one season of maize	0
SMN_1	One season of soybean followed by one season of maize	50
SMN_2	One season of soybean followed by one season of maize	75
SMN_3	One season of soybean followed by one season of maize	150
SMN_4	One season of soybean followed by one season of maize	200
MMN_0	Two seasons of maize	0
MMN_1	Two seasons of maize	50
MMN_2	Two seasons of maize	100
MMN_3	Two seasons of maize	150
MMN_4	Two seasons of maize	200

Each plot was therefore planted for two seasons and each treatment replicated three times among the three selected farmers to reduce experimental errors. All the three farmers in Siaya namely; Jacob, Asango and Evalyne were in the cluster for ease of management and monitoring of the trials, each farmer having 45 plots making a total of 135.

3.3 Field layout

The layout after randomization of treatments in all sites in the field is shown below;



	Site 1-Asango PLOT 1	Site 1-Asango PLOT 2	Site 1-Asango PLOT 3	Site 2-Evelyn PLOT 1	Site 2-Evelyn PLOT 2	Site 2-Evelyn PLOT 3	Site 3- Jacob PLOT 1	Site 3- Jacob PLOT 2	Site 3- Jacob PLOT 3
REP 1	AMN$_0$	S MN$_1$	MMN$_3$	M MN$_3$	AM N$_2$	SMN$_2$	SMN$_0$	MMN$_4$	AM N$_3$
	AMN$_3$	SMN$_3$	MM N$_2$	MMN$_0$	AM N$_0$	S MN$_0$	SM N$_1$	M MN$_0$	AMN$_0$
	AMN$_1$	SMN$_4$	MMN$_0$	MMN$_4$	A MN$_1$	SMN$_4$	SM N$_2$	MMN$_3$	A MN$_1$
	A MN$_4$	SMN$_2$	MMN$_1$	MM N$_1$	A MN$_4$	S MN$_3$	S MN$_4$	M MN$_1$	AMN$_2$
	AMN$_2$	SMN$_0$	MMN$_4$	MMN$_2$	AMN$_3$	SMN$_1$	SMN$_3$	MMN$_2$	AMN$_4$
REP 2	MMN$_4$	AMN$_0$	SMN$_3$	SMN$_1$	MMN$_4$	AMN$_4$	AMN$_O$	SMN$_2$	MMN$_2$
	MMN$_0$	AMN$_3$	SMN$_1$	SMN$_2$	MMN$_1$	AMN$_O$	AMN$_1$	SMN$_3$	MMN$_2$
	MMN$_3$	AMN$_4$	SMN$_2$	SMN$_0$	MMN$_0$	AMN$_1$	AMN$_3$	SMN$_1$	MMN$_4$
	MMN	AMN$_1$	SMN$_4$	SMN$_4$	MMN$_3$	AMN$_4$	AMN$_4$	SMN$_0$	MMN$_3$
	MMN$_1$	AMN$_2$	SMN$_0$	SMN$_3$	MMN$_2$	AMN$_3$	AMN$_2$	SMN$_4$	MMN$_2$
REP 3	SMN$_4$	SMN$_1$	AMN$_2$	MMN$_3$	SMN$_3$	AMN$_0$	MMN$_0$	AMN$_3$	SMN$_2$
	SMN$_0$	AMN$_2$	AMN$_3$	MMN$_4$	SM N$_2$	AMN$_2$	MMN$_2$	AMN$_1$	SMN$_4$
	SMN$_3$	MMN$_4$	AMN$_1$	MMN$_0$	SMN$_O$	AMN$_4$	MMN$_4$	AMN$_2$	SMN$_0$
	SMN$_1$	AMN$_0$	AMN$_0$	MMN$_2$	SMN$_4$	AMN$_3$	MMN$_3$	AMN$_4$	SMN$_3$
	SMN$_2$	MMN$_3$	AMN$_4$	MMN$_1$	SMN$_1$	AMN$_3$	MMN$_1$	AM N$_0$	SMN$_1$

Where; A=Amaranth, S=Soybean, M=Maize, N=Nitrogen, 0=0 Kg N ha^{-1}, 1=50 Kg N ha^{-1}, 2=100 Kg N ha^{-1}, 3= 150 Kg N ha^{-1}, 4=200 Kg N ha^{-1}.

Figure 2: A sketch of the actual field layout installed in each of the sites.

3.4 Soil sampling and analysis

Before planting, soil sample at a depth of 0-30cm was taken randomly from the experimental field. The collected sample was composited to one sample, air-dried, ground, and sieved using 2mm sieve. Then the composite sample was analyzed at the University of Eldoret soil laboratory to determine the selected physicochemical properties i.e soil pH, organic matter (OM), total nitrogen (TN), available phosphorus (Ava P) and soil texture according to Okalebo et al., 2002.

3.4.1 Soil pH

The Measurements of pH was done and was expressed as the inverse log of the hydrogen ion concentration measured on 2.5:1 soil to water suspension on a glass electrode.

3.4.2 Soil texture

Soil particle density which is the measure of sand (2.00 - 0.05 mm), silt (0.05 - 0.002 mm) and clay (< 0.002 mm) fractions was performed using the hydrometer method. The process involves the dispersion of soil into individual particles. Individual soil particles are often bound into aggregates hence the requirement for dispersion. Based on the proportions of different particle sizes, a soil textural category may be assigned to the sample. The hydrometer method of silt and clay measurement relies on the effects of particle size on the differential settling velocities within a water column. The settling velocity is also a function of liquid temperature, viscosity and a specific gravity of the falling particle.

3.4.3 Total Nitrogen

Measurement of total N was carried out by digesting the soil sample using hydrogen peroxide+ sulphuric acid, selenium and salicylic acid. The principle takes into account the possible loss of nitrates by coupling them with salicylic acid in an acid media to form 3 nitro salicylic and or 4-nitrosalicylic. The compounds are then reduced to their corresponding amino acid forms by the soil organic matter. The Analysis of total nutrients required complete oxidation of organic matter. The hydrogen peroxide oxidized the organic matter while the selenium compound acted as a catalyst for the process and the H_2SO_4 completed the digestion.

3.4.4 Available P

Available P was determined using Olsen, (1954) method. The principle behind this method is that the soil is extracted with 0.5 M solution of sodium bicarbonate at pH 8.5. In calcareous, alkaline or neutral soils containing calcium phosphate, this extractant decreases the concentration of Ca in solution by precipitating Ca as $CaCO_3$. The result is an increase in the P concentration in the solution. In acid soils containing Al and Fe phosphate, the P concentration in the solution increases as the pH rises. Precipitation reactions in acid and calcareous soils are reduced to a minimum because the concentrations of Al, Ca and Fe remain at a low level in this extractant.

3.4.5 Organic carbon

Organic carbon was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation from the heat of solution and external heating, the unused or residual $K_2Cr_2O_7$ (in oxidation) was titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$, the difference between added and residual $K_2Cr_2O_7$, gave a measure of organic C content of the soil. The chemical reaction in the method is;

$2Cr_2O_7 + 3C + 16\ H+ \rightarrow 4Cr3+ 3CO_2 + 8\ H_2O$

3.5 Crop Husbandry

3.5.1 Land preparations and planting

During the first season, ploughing of land was done followed by harrowing to the required tilt. Maize seeds (KSTP 94) were sowed at a spacing of 75cm x 25cm. Each hill was placed two seeds and later thinned to one seedling at 4 leaf stage to give a plant population of 53,333 plants ha^{-1}. The maize variety was tolerant to high temperature and matured faster (140 days). The grain amaranth seeds were obtained from KALRO-Kakamega while the nitrogen fertilizer (urea) and phosphorous fertilizer (TSP) was obtained from reputable agro-dealer in Kakamega.

Soybean (Soybean variety TGX 1740-2F (SB19) and grain amaranth (golden) seeds were drilled along ridges (and straight lines on the flat) and were later thinned to have plants within 5 cm of each other with an inter-row spacing of 75 cm to achieve a population of 266,000 plants ha-^{1}. Sole maize was planted during the second season in all plots using TSP fertilizer at of 26kg P ha-^{1}.

3.5.2 Fertilizer application

During the first season, the blanket application of 26kg P ha-^{1} in form of TSP (Triple superphosphate) and 50 kg N/ha in form of urea were applied to all plots at planting by side banding at about 5 cm away from the seed and at about 5 cm deep on the ridge.

During the second season, Nitrogen was applied using a spot application method at 0, 50, 100, 150 and 200kg rate of N ha-^{1} using urea (46%N). The N fertilizer was applied in split application i.e. 1/3rd at planting and 2/3rd top dressing at 6 weeks after planting. Millar *et al*. (2010) reported that fertilized crops take up less than50% of the

N applied, leaving the excess available for loss. Therefore, a split application of N was used to reduce the nitrogen losses.

3.5.3 Thinning and gapping

This was carried out early to ensure one seedling per hill and avoid unnecessary competition. Gapping was also done to replace seedlings that failed to germinate.

3.5.4 Weeds and Pest control

One hoe weeding was undertaken 3 weeks after planting (3WAP), followed by careful hand pulling of other weeds which were carried out at 7 WAP**.** Bulldock and gladiator insecticides were used to control stalk borers, mites, bugs weevils and termites in maize, soybean and grain amaranth.

3.5.5 Harvesting

Soybean was harvested when the pods had turned brown (Dugje*et al*., 2009). Maize was harvested at 12 WAP when the leaves turned yellowish and fallen off which were signs of leaf senescence and cob maturity. All maize stover and ears (above-ground biomass) were weighed in the site using a hanging balance. Harvesting was done when all the plants had reached maturity and flower heads had turned brown. Grain amaranth was harvested at maturity, by cutting off the inflorescences and placing them in separate containers, dried and threshed to obtain the grain.

3.6 Data collection

The data on *Striga* weed intensity on each experimental unit was collected at eight weeks after planting (8 WAP) and twelve weeks after planting (12 WAP). Number of *Striga* counted in one-meter-square of each net plot to compare the infestation level.

Data was collected on maize crop height (HC) at 8 WAP and 12 WAP and dry weights of grains (DW) collected at harvesting. Plant height was measured from ten randomly taken plants from the middle two rows at 8WAP and 12WAP from the ground level to the base of the panicle.

All plants of the net plot area (1m^2) were harvested to determine grain yield per plot which was converted to per hectare bases and adjusted to 12.5% moisture level. Above ground, dry biomass weight was determined at harvesting time from the plants taken from the net plot.

On maturity, grain amaranth and soybeans were harvested, taken to the University dried and the grain weights taken.

3.7 Economic Analysis

Economic analysis was made using the prevailing inputs at planting and for outputs, at the time the crop was harvested. The analysis was based on;

i. Mean grain yield is the average yield (kg ha^{-1}) of each treatment.
ii. The gross benefit per hectare is the product of field price of maize, grain amaranth, soybean and the mean yield for each treatment.
iii. The Total Variable Costs (TVC) is the sum of the field cost of production.

iv. The net benefit per ha (NB) for each treatment was the difference between the gross benefit and the total variable costs.

3.8 Statistical analysis

Analysis of variance was done to compare the effects of the different treatments on *Striga* intensity and maize performance using Genstat 14th edition. Fisher's least significant difference (LSD) test was used to separate the means ($P < 0.05$).

The model that was followed for data analysis was;

Yijklr =μ+Ai+ S_j+M_K+βl+ (ASMβ)ijkl+N_r+ (ASMN)ijklr+εijklr

Where,

Yijklrx= Observation on *Striga* intensity and maize performance

- μ=Overall means
- A_i =Effects due to grain amaranth
- $S_{j=}$Effects due to soybean
- M_K=Effects due to maize
- B_L=Block effects
- (ASMβ)ijkl =Main plot error term
- N_r=Effects due to nitrogen levels
- (ASMN)ijklr=Sub plot error
- εijklr=Main plot and subplot interactions error term.

CHAPTER FOUR

RESULTS

4.1. Soil Characteristics

The soil of trial sites 1&3 was moderately acidic (Table 3). The soilon site 2 had strongly acidic nature (pH 4.97).Organic carbon of the experimental sites in all sites was in the medium category according (1.5 to 3%). Total N in all sites was moderate. Available P at all the sites was at low levels (<10mg/kg). All the soils fell in the sandy loam textural class. The table below shows the measured soil parameters.

Table 3. Physio-chemical characteristics of the topsoil (0 to 30 cm) of the Experimental fields.

Parameter	Site 1(Asango)	Site 2(Evelyn)	Site 3(Jacob)
Soil Ph	5.32	4.97	5.44
Organic C (%)	1.63	1.58	1.91
Total N (%)	0.13	0.12	0.15
AvailableP (mg/kg)	8.44	8.13	8.56
Texture			
Sand (%)	43	46	47
Clay (%)	41	39	41
Silt (%)	16	15	12
Textural class	Sandy loam	Sandy loam	Sandy loam

4.2 Effects of crop rotation and nitrogen fertilizer on *Striga* intensity.

There was a significant difference due to crop rotation and nitrogen on *Striga* intensity both at 8WAP and 12 WAP. However, crop rotation systems interacting with nitrogen did not vary significantly on *Striga* intensity (m^2) both at 8WAP and 12

WAP (appendix I&II).The *Striga* weed count was higher in maize-maize crop rotation system than in amaranth-maize and soybean-maize system at all levels of N at both 8 WAP and 12 WAP. Soybean- maize rotation without N fertilizer resulted to 41.2% reduction on *Striga* count while amaranth-maize rotation at no N fertilizer resulted in 34.4% reduction on *Striga* at 12WAP as compared to that produced from the maize-maize rotation at no N fertilizer. The highest *Striga* number (31.44/ m^2) at 12 WAP was observed on maize-maize crop rotation system without N fertilizer while the lowest (6.89/ m^2) at 12 WAP was observed on soy bean-maize crop rotation system at 200 kg N ha^{-1}. Table 4 and 5 below shows the effect of crop rotation and N rates on *Striga* intensity at 8 WAP and 12 WAP respectively.

Table 4: Effect of crop rotation and nitrogen fertilizer on *Striga* intensity (m^2) at 8WAP

N rates (Kg ha-$^{1)}$

	0	50	100	150	200	**Crop rotation means**	Lsd (0.05)	CV%
Crop rotation							**2.51**	**22.7**
Maize-maize	21.11a	18.56d	15.78d	15.78m	12.44e	**17.33**		
Grain amaranth-maize	13.56b	12.44e	12.44e	10.56k	8.44g	**11.49**		
Soybean-maize	14.44c	11.56e	8.33g	8.33ab	4.89f	**9.42**		
N means	**16.37**	**14.19**	**13.19**	**11.41**	**8.59**			
Lsd	**2.81**							
CV%....**8.7**								

Note: WAP-Weeks after planting, Lsd= least significant difference, CV= coefficient of variation, Means followed by same letters within the column are not significantly different (P ≤0.05).

Table 5: Effect of crop rotation and nitrogen fertilizer on *Striga* intensity (m^2) at 12WAP.

N rates (Kg ha-$^{1)}$

	0	50	100	150	200	**Crop rotation means**	Lsd (0.05)	CV %
Crop rotation							**3.35**	**22.7**
Maize-maize	31.44i	27.33hi	23.44gh	22.11fg	16.00cde	**24.07**		
Grain amaranth-maize	20.67efg	19.33defg	17.33def	14.67bcd	14.67bcd	**16.31**		
Soybean-maize	20.67efg	15.67cde	11.67abc	10.00ab	6.89a	**12.98**		
N means	**24.26**	**20.78**	**17.48**	**15.59**	**10.81**			
Lsd	**3.45**							
CV%....**8.3**								

Note: Lsd= least significant difference, CV= coefficient of variation, Means followed by same letters within the column are not significantly different (P ≤0.05).

There were no significant differences on treatment and site interaction on *Striga* count.

Grain amaranth-maize rotations resulted to lower *Striga* intensity at all levels of N as compared to maize monocrop at similar levels of N. Means for crop rotations and nitrogen varied significantly (Table 4 & 5). Maize monocrop at all levels of N demonstrated the highest *Striga* intensity as compared to soybean-maize and grain amaranth maize rotations at all levels of N.

4.3. Effects of crop rotation and nitrogen fertilizer on maize growth and maize yield parameters.

4.3.1 Plant height

The results indicated that there was a significant difference in maize plant height due to crop rotation and nitrogen ($P \leq 0.05$) at 8WAP and 12WAP. Similarly, interactions of crop rotation and nitrogen significantly (Appendix III & IV). Maize height for maize monocrop and that of grain amaranth – maize rotation without N fertilizer were not significantly different. Similarly, all crop rotations at 200 kg N ha-^{1}were not significantly different. It was observed that there was an increase in plant height with an increase in nitrogen level both at 8 weeks and 12 weeks after planting for all the crop rotation systems. The tallest plant (151.90 cm) at 8WAP and (238.90 cm) at 12WAP was recorded from amaranth- maize rotation at 200 kg N ha-^{1}and the shortest (106.7 cm) at 8 WAP and (189.7 cm) at 12 WAP was from the grain amaranth-maize rotation without N application. Table 6 & 7 below shows the effect of crop rotation and N fertilizer on maize height at 8 WAP and 12 WAP.

Table: 6 Effects of crop rotation and nitrogen fertilizer on the height (cm) of maize at 8 WAP.

N rates (Kg ha-$^{1)}$

	0	50	100	150	200	**Crop rotation means**	Lsd (0.05)	CV %
Crop rotation							**11.60**	**7.5**
Maize-maize	108.33a	113.00ab	126.00cd	139.22fgh	147.33gh	**129.64**		
Grain amaranth-maize	106.67a	122.00bc	125.56cd	142.11def	1151.89efg	**126.78**		
Soybean-maize	126.22cd	133.56de	145.89fg	147.44fg	146.89fg	**140.00**		
N means	**113.74**	**122.85**	**132.48**	**142.93**	**148.70**			
Lsd	**5.8**							
CV%....**3.9**								

Note: Lsd= least significant difference, CV= coefficient of variation, Means followed by same letters within the column are not significantly different (P ≤0.05).

Table 7: Effects of crop rotation and nitrogen fertilizer on the height(cm) of maize at 12WAP.

N rates (Kg ha-$^{1)}$

	0	50	100	150	200	**Crop rotation means**	Lsd (0.05)	CV %
Crop rotation							**71.90**	**8.10**
Maize-maize	198.60ab	196.20a	216.20cd	229.06f	233.10f	**253.20**		
Grain amaranth-maize	190.07a	188.0cde	208.35bc	227.04def	239.09f	**214.40**		
Soybean-maize	209.40c	216.10cd	233.30f	233.90f	237.30f	**226.00**		
N means	**199**	**200.30**	**219.31**	**229.00**	**236.13**			
Lsd	**77.80**							
CV%....**8.5**								

Note: Lsd= least significant difference, CV= coefficient of variation, Means followed by same letters within the column are not significantly different (P ≤0.05).

4.3.2 Yield of maize

There was a significant difference (P ≤ 0.05) due to crop rotation systems and nitrogen on the yield of maize and (Table 8).However, the interaction of crop rotation and nitrogen did not vary significantly on maize yields (tons ha^{-1}). There was an increasein maize yield on all the crop rotation system with an increase in N levels from 0-200kgN ha-^{1}.On the effect of crop rotation, maize succeeding soybean resulted in higher yields compared to maize succeeding amaranth and maize monocrop. Soy bean-maize rotation interacting with 200kgN ha-^{1}of resulted in the highest yield (5.23tons ha-^{1}) while rotation involving maize-maize at 0 kg N ha-^{1} resulted in the lowest yields (1.85 tons ha-^{1}). However, there was no significant difference in maize grain yield for grain amaranth-maize crop rotation at 150 kg ha-^{1} and that of soybean-maize rotation systems at 150kg N ha-^{1}and 200kg N ha-^{1}. This illustrates that for economic purpose, 150kg N ha-^{1}for two cropping system is recommendable. Effects of crop rotation and nitrogen fertilizer on maize grain yield are shown in the table below:

Table 8: Effects of crop rotation and nitrogen fertilizer on maize grain yield (tons ha-^{1}).

N rates (Kg ha-$^{1)}$

	0	50	100	150	200	**Crop rotation means**	Lsd(0.05)	CV %
Crop rotation							**0.24**	**12.8**
Maize-maize	1.85a	2.26 ab	2.99cd	3.85 fgh	4.19 hi	**3.03**		
Grain amaranth-maize	2.68ab	3.33 de	3.94gh	4.49j	4.63 i	**3.82**		
Soybean-maize	3.41cd	3.63efg	4.23hi	5.15j	5.26 j	**4.34**		
N means	**2.65**	**3.08**	**3.73**	**4.50**	**4.70**			
Lsd **0.27**								
CV%........**3.2**								

Note: Lsd= least significant difference, CV= coefficient of variation, Means followed by same letters within the column are not significantly different ($P \leq 0.05$).

Though lower than soybean-maize rotation, amaranth-maize crop rotation at all level of N resulted in higher maize yield than in maize-maize crop rotation at similar levels of N.

There was a significant difference ($P \leq 0.05$) in maize grain yield among the experiments. The highest grain yield in sole maize cropping (4.19tons ha-^{1}) was obtained with application of 200 kg N ha-^{1} whereas the lowest grain yield (1.852 tons ha-^{1}) was obtained from the same cropping system without application of nitrogen fertilizer.

Grain amaranth-maize rotation system interacting with 200kg N ha-^{1} resulted in 10.5% maize yield increase while soybean-maize system interacting with 200kg N ha-^{1} resulted in 25.7% increase in maize yield as compared to maize-maize crop rotation system interacting with 200kg N ha^{-1}. There was no significant ($P \leq 0.05$) difference in maize yields in grain amaranth-maize and soybean maize rotations at 150kg N ha-^{1} (Table 8).

4.3.3 Yield of maize Stover

There was a significant difference ($P \leq 0.05$) due to crop rotation systems, nitrogen on the yield of maize stover (Table 9). Similarly, there was a significant difference in crop rotation and nitrogen interactions on maize stover(appendix VI).Stover for maize succeeding soybean was the highest followed by stover for maize succeeding grain amaranth and the least stover was from maize monocrop. The highest maize stover yield was obtained from soybean-maize rotation (14.06 tons ha-$^{1)}$ at 200 Kgs N ha-^{1}. Stover for maize succeeding maize exhibited the lowest stover yield (8.38 tons ha-^{1}). The table below the effect of crop rotation and N fertilizer on maize yield stover.

Table 9: Effect of crop rotation and nitrogen fertilization on the yield of maize stover.

N rates (Kg ha-$^{1)}$

	0	50	100	150	200	**Lsd (0.05)**	**CV %**
Crop rotation						**0.30**	**3.5**
Maize-maize	8.35 a	9.95c	11.38 d	12.20ef	**11.01**		
Grain amaranth-maize	8.92 b	10.33 de	11.61 d	11.81 de	**11.16**		
Soybean-maize	11.54 d	11.43d	12.58f	13.43g	**12.61**		
N means	**9.60**	**10.57**	**11.56**	**12.48**	**13.45**		
Lsd	**0.43**						
CV% 2.7							

Note: Lsd= least significant difference, CV= coefficient of variation, Means followed by same letters within the column are not significantly different (P ≤ 0.05).

There was no significant difference (P ≤ 0.05) in stover weight in soybean – maize rotation at 150 kg N ha-^{1} and that of maize- maize and amaranth –maize rotation systems at 200kgN ha-^{1}. The effect of N was significantly different among the crop rotations.

4.3.4 Effects of nitrogen on *Striga* weed intensity, maize yield and yield components of maize.

There was a significant (P ≤ 0.05) decrease in the population of *Striga* weed with an increase of N rates from 0-200kg ha-^{1} for all the crop rotation systems. Similarly, the decrease in *Striga* was observed to increase maize grain yield in all the crop rotation systems and vice-versa.

4.4 Effects of the site on *Striga* count, maize yield and maize yield parameters

Variation in maize height, grain and stover yield was observed between the three sites in all the treatments. Maize yield and yield parameters were observed to be higher in site 3 and lowest in site 2 (Table 9). A negative relationship between *Striga* weed intensity and maize yield and yield parameters was evident whereby the increased intensity of *Striga* weed resulted in a reduction in maize yield and yield parameters in all the treatments and vice-versa.

Similarly, there was a significant difference ($P \leq 0.05$) in *Striga* intensity between the sites across all the treatments site 3 showing the lowest levels of the weed and site 2 having the highest. The table below shows the effect of site on *Striga* intensity and maize performance,

Table 10: Table of the site means for Striga count, maize yield, maize height and maize stover weight.

	Maize Height(cm) at 12 WAP			Maize Stover (tons/ha)			Maize grain yield (tons/ha)			Striga population (m^2) at 12WAP		
	Site			Site			Site			Site		
Treatment	1	2	3	1	2	3	1	2	3	1	2	3
MMN_0	197	195	204	8.18	8.66	8.20	1.40	1.95	2.20	33.00	34.67	26.67
MMN_1	206	197	210	9.14	9.92	10.78	2.40	1.75	2.63	30.00	28.00	24.00
MMN_2	214	213	222	11.34	11.28	11.50	3.19	2.40	3.40	18.00	20.00	14.00
MMN_3	238	220	241	12.57	11.44	12.58	3.47	3.48	4.61	18.00	22.33	16.00
MMN_4	217	236	246	13.06	12.99	13.44	4.02	3.91	4.63	16.00	21.00	11.00
AMN_0	199	193	203	8.56	9.75	8.43	2.56	2.53	2.96	18.00	23.00	15.00
AMN_1	217	213	218	10.07	9.90	11.01	3.31	3.22	3.46	20.00	24.00	14.00
AMN_2	194	218	214	11.50	11.72	11.61	3.99	3.73	4.10	18.00	20.00	14.00
AMN_3	210	231	238	11.45	11.90	12.08	4.40	4.37	4.71	19.00	8.00	17.00
AMN_4	222	250	245	12.89	12.89	12.89	4.59	4.37	4.93	9.67	13.00	6.00
SMN_0	192	214	222	11.59	11.39	11.64	3.42	3.33	3.48	20.00	22.00	14.00
SMN_1	198	223	228	10.08	11.67	12.54	3.67	3.57	3.67	17.00	20.00	10.00
SMN_2	236	223	240	11.70	12.49	13.54	4.34	3.96	4.41	13.00	15.00	7.00

SMN$_3$	242	239	245	13.37	13.03	13.87	5.26	5.02	5.17	11	13.00	6.00
SMN$_4$	248	242	247	13.57	13.96	14.62	5.11	5.46	5.22	1.33	15.33	4.00
Means	**227 221 246**			**11.28 11.00 12.61**			**3.68 3.54 3.97**			**18.02 22.02 13.31**		
CV (%)	8.1			3.5			12.8			22.7		
Lsd (0.05)	59.6			0.1722			0.2010			2.0600		

Note: WAP-Weeks after planting, Lsd= least significant difference, CV= coefficient of variation. All sites (the three farmers) were in Ligega village, Ugunja Sub County, Siaya County.

Similarly, the sites differed significantly ($P \leq 0.05$) in influencing the numbers of *Striga* populations at 8WAP and 12WAP. However, treatment interacting with site did not differ, showing that their contribution to the *Striga* population is insignificant.

4.5 Grain yield of amaranth and soybean.

The average yield for grain amaranth was 2.23 kg ha^{-1}. The yield did not vary significantly among the farmers. The highest yield was obtained in site 3 having 2.46 tons ha $^{-1}$ and the lowest in site 2 (1.97 tons ha^{-1}). The highest yield for soybean was 2.81tons ha $^{-1}$ (site 3) and the lowest 1.92 tons ha^{-1}(site 1). There was also significant variation in yields of soybean among the sites. The table below shows the yields of grain amaranth and soybean in the three sites.

Table 11: Yields of grain amaranth and soybean in all the sites

Crop	Site 1	Site 2	Site 3	Average (tons/ha)
Grain amaranth ton/ha	2.14a	1.97b	2.46a	**2.19**
Soybean tons/ha	1.98a	1.92a	2.81b	**2.23**

Note : Means followed by same letters within the crow are not significantly different ($P \leq 0.05$).

4.6 Economic analysis

The highest net returns were obtained from soy bean-maize crop rotation system (Ksh 202,240) at 150 kg ha $^{-1}$N (table 12). The highest returns in grain amaranth-maize rotation (Ksh 171,040) was obtained by application of 200kg ha $^{-1}$ Maize- maize crop rotation at 0k ha^{-1} N resulted in the lowest net returns (Ksh 42,550) with the highest in the same crop rotation system (Ksh124, 831) being obtained at 200kg ha^{-1} N. The average of grain amaranth and soybean from the three sites were used, the reason their values in table 12 are constant. The table below shows the cost economic analysis for grain amaranth –maize rotation, soybean – maize rotation and maize monocropping.

Table 12: Economic analysis

	MM N_0	MM N_1	MM N_2	MM N_3	MM N_4	AM N_0	AM N_1	AM N_2	AM N_3	AM N_4	SM N_0	SM N_1	SM N_2	SM N_3	SM N_4
Gross returns															
Maize yield (kg/ha)	1,852	2,261	2999	3854	4189	2683	3330	3942	4497	4630	3410	3639	4239	5152	5267
Income from maize/ha(yield*Ksh25/kg)	92,600	113,050	149,950	192,700	209,450	67,075	83,250	98,550	112,425	115,750	85,250	90,975	105,975	128,800	131,675
Grain amaranth yield(kg/ha)						2190	2190	2190	2190	2190					
Income from G.amaranth/ha(yield*KES 55/kg)						120,450	120,450	120,450	120,450	120,450					
Soybean yield (kg/ha)											2230	2230	2230	2230	2230
Income from soybean/ha (yield*KSh 50/kg)											135,000	135,000	135,000	135,000	135,000
TOTAL/HA/YEAR(KSH)	92,600	113,050	149,950	192,700	209,450	187,525	203,700	219,000	232,875	236,200	220,250	225,975	240,975	263,800	266,675
Cost of production															
Cost of maize seeds/ha (25kg*Ksh100/kg)	5,000	5,000	5,000	5,000	5,000	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Cost DSP fertilizer/ha	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Cost of Urea fertilizer/ha		8,640	17,280	25,920	34,560		4,320	8,640	12,960	17,280		4,320	8,640	12,960	17,280
Cost of G.amaranth seeds/ha (6kg/ha*Ksh 55)						330	330	330	330	330					
Cost of soy bean seeds/ha (21kg/ha*Ksh 50)											1,050	1,050	1,050	1,050	1,050
Other cost/ha (dominant cost															

e.g., planting,															
Weeding, harvesting, land preparation etc.)	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050	29,050
TOTAL	50,050	58,690	67,330	75,970	84,619	47,880	52,200	56,520	60,840	65,160	48,600	52,920	57,240	61,560	65,880
NET PROFIT	42,550	54,360	82,620	116,730	124,831	139,645	151,500	162,480	172,035	171,040	171,650	173,055	183,735	202,240	200,795

CHAPTER FIVE

DISCUSSIONS

5.1Effects of crop rotation andnitrogen fertilizer on *Striga* intensity.

Striga intensity in maize grown after soybean and grain amaranth reduced significantly compared to maize monocropping .Soybean - maize crop rotations demonstrated the lowest intensity of *Striga* at all level of nitrogen in all sites compared to amaranth-maize and maize-maize rotations. The high reduction in *Striga* weed intensity in soybean plots could have been due to; suicidal germination of *Striga* effect of soybean that reduces *Striga* seed bank and soybean ability to fix nitrogen. Carsky *et al*. (2002) reported that *S. hermonthica* incidence in maize after soybean, compared to maize after sorghum, was significantly ($P \leq 0.05$)) reduced from 3.2 to 1.3 emerged *Striga* plants per maize plant, resulting in greatly improved grain yields. Similarly, Sanginga *et al.* (2003) reported that the grain yield of maize grown after soybean was increased by an average of 25%. Maize under soybean rotation was probably more robust due to green manuring effect of soybean. Soybean induces germination of *S. hermonthica* but is not parasitized (Carsky*et al.* 2002; Odhiambo *et al.* 2011; Sanginga *et al*. 2003) making the legume a good choice for crop rotation in *Striga* spp. management. Soybean being a legume fixes nitrogen and improves soil fertility.

The reduction in *Striga* weed intensity in grain amaranth-maize rotation than in maize-maize rotation indicated that amaranth has the ability to induce suicidal germination of *Striga*. Grain amaranth could have caused suicidal germination of *Striga* weeds during the first season reducing their seed bank and reduction in their population in the second season. According to Alabi, (2007), laboratory screening of

Amaranthus lines showed that it can induce suicidal germination of *Striga* seeds. Grain amaranth is a non-leguminous pseudo-cerealcrop and its use in combination with nitrogen fertilizer contributed greatly to the reduction in *Striga* intensity as well as increased maize yield. This implies that grain amaranth-maize system is economical compared to maize monocropping and can be adopted by farmers.

The high intensity of *Striga* in maize-maize rotation system was due to the availability of weed host i.e. maize thus *Striga* weed established, matured and flowered producing more seeds during the first season. This was evident by the higher number of *Striga* weed during the second season. However, the effects of nitrogen on *Striga* weed was evident where the weed's intensity reduced as the level of nitrogen was increased from 0-200kg N ha^{-1} in maize mono-cropping. The high *Striga* count in the maize-maize treatment could have been responsible for the low maize yield. *Striga* weed attachments on crops cause high levels of yield reduction, (Abdul *et al.*, 2012).

Striga intensity decreased in all the three crop rotation systems with an increase of N rates from 0-200kg N ha^{-1} N fertilizer played a major role in determining the intensity of *Striga* population both at 8WAP and 12WAP. Gacheru and Rao, 2001 reported that nitrogen has the effect of reducing strigolactones production from the host plants and therefore inhibits germination and subsequent attachment of *S. hermonthica*seeds to the host.

5.2 Effects of crop rotation andnitrogen fertilizer on maize growth and maize yield parameters.

Higher heights in maize succeeding soybean and amaranth than in maize monocrop can be attributed to reduced *Striga* parasitism. Both soybean and grain amaranth reduced Striga seed bank during the first season. *Striga* attachment on maize inhibits maize cells elongation in meristematic cells resulting in short internodes and stunted growth, this explains why plant height of maize increased with lower *Striga* numbers among the three crop rotations. Also, lower *Striga* numbers do not adversely affect the nutrient absorption status of the crops.

There were significant differences in maize yield among the treatments with soybean-maize rotation demonstrating higher yields followed by grain amaranth-maize rotation at all levels of N. This could be attributed to a reduction in *Striga* intensity in soybean-maize/amaranth-maize crop rotation systems that consequently reduced parasitism on maize hence increasing maize yield. Incorporating legume into a cropping cycle rotation improves soil physical conditions and biological properties which may affect growth factors other than N and P nutrition. Maize yield increases ranging from 20 to 130 % have been reported for maize grown after soybean relative to maize grown after maize (Sanginga *et al*., 2003). These rotation effects were mostly ascribed to N carry-over effect, but some authors have suggested that rotational effects of legumes on a subsequent crop go beyond improved nutrition (Vanlauwe *et al.*, 2003; Sanginga *et al.*, 2003). Several other workers have reported improved maize yield after a crop of legume in the same agro-ecological zone (Carsky *et al.*, 2002, Sanginga *et al*., 2002). The lower maize yield in sole maize rotation was due to the high *Striga* numbers that affect the grain yield of maize. *Striga* attaches itself to the roots of host plants and syphons the nutrients and water intended for plant growth.

The high maize stover yield in soybean –maize rotations could be attributed to the ability of soybean to fix nitrogen which largely contributes to plant biomass, unlike grain amaranth and maize. According to (Giller, 2011), soybean has high nitrogenfixing potential and soil-improving properties. Similarly, the low maize stover yield in maize-maize rotation at 0 Kgs ha^{-1} nitrogen was due to (1) insufficient plant growth elements especially N which is required for vegetative growth and (2) high intensity of *Striga* due to host presence in the two seasons as well as low N that favours *Striga* establishment and therefore high parasitism on maize.

The possible reason for the increase in grain yield with an increase in N levels application in all crop rotations might be due to the increase of nutrient uptake of the crop as well as reduced *Striga* infestation. N also increases the vegetative growth of the host plant, which strengthens it and protects the plant from *Striga* parasitism. It is already known that nitrogen reduces the severity of *Striga* attack while increasing the host yield simultaneously (Agabawi and Younis, 1965; Ogborn, 1984). A similar finding on the positive effect of increased maize yield with increased rates of N was reported by Kandil, (2013). When N is limiting in soils, its uptake has a tremendous influence on grain yield of maize.

5.4 Grain yield of amaranth and soybean.

There was no significant difference in the yield of grain amaranth among the sites and this was attributed to uniformity in soil fertility status in the sites. Grain amaranth breeding programs in Latin America have achieved yields of 7200 kg ha-^{1} and 4600 kg ha-^{1} for certain varieties in Peru and Mexico, respectively (Brenner et *al.*, 2000). Variability in Amaranth grain yields depends on factors such as soil chemical and physical properties, climate, planting density, planting time, variety, and level of fertilization. Studies show that nitrogen is the most limiting nutrient under most environments and the addition of nitrogen either as chemical fertilizer or manure significantly improves the growth and yields of grain amaranth. Soybean production in Kenya is estimated at 8,000 mt /yr, with 80% of the volume produced in western Kenya (Keino *et al.*, 2015). Productivity in western Kenya remains low with average yields of 600 kg/ha against the potential yields of 3,000 kg ha-^{1} (Mahasi *et al*., 2011), and this is attributed to declining soil fertility.

5.5 Economic analysis

Crop rotation of soybean and maize achieved the highest economic returns of Ksh.202, 240 per hectare. This can be attributed to the reported ability of soybean to cause suicidal germination hence reduced parasitism on maize that leads to higher grain yield. This was followed closely by grain amaranth-maize rotation giving net returns of Ksh.171, 040 per hectare. The maize-maize rotation was the lowest at Ksh.124, 831. The low returns in maize monocropping can be attributed to the low yield of maize grain due to high *Striga* infestation. *Striga* parasites on maize depleting nutrients and water, leading to low grain production. The implications are that grain amaranth-maize rotation increased net returns by Ksh.47, 209 per hectare which is a 27% increase as compared to maize mono-cropping. This amount is almost enough for a farmer in that area to purchase di-ammonium phosphate (DSP) fertilizer, maize seeds and cover another production cost for a hectare of land for the next crop rotation.

As compared to maize, grain amaranth is more nutritious and can be used to substitute the expensive animal protein which most subsistence farmers cannot afford. The crop is low demanding and can withstand soils of low fertility, hence farmers can use locally available organic manure to minimize the cost of production. The results also indicate that involving grain amaranth in crop rotation significantly reduced *Striga.* The ability to control *Striga* reduces the burden of pesticides cost over the years.

Generally, diversification of crops will help cushion farmers against losses due to pest infestation as well as price fluctuations.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

- Grain amaranth has the ability to induce suicidal germination of *Striga*.
- From this study, soybean-maize crop rotation interacting with 200 kg N ha^{-1} had the lowest *Striga* population. Similarly, though lower than soybean-maize; grain amaranth-maize crop rotation interacting with 200 kg N ha^{-1}reduced*Striga* infestation more than maize monocrop at the same level of N. The highest *Striga* population was exhibited in maize –maize crop rotation. From the results obtained, therefore, it can be concluded that the use of grain amaranth and N fertilizer is also effective in the control of *Striga*.
- Including soybean and grain amaranth in the crop rotation increased maize yield significantly compared with maize monocrop because of reduced *Striga* population.
- Application of N fertilizer significantly reduced *Striga* population and increased maize yield significantly in all the crop rotations. This, therefore, demonstrated the ability of N to reduce the *Striga* weeds population. From this study 200 kg, N ha^{-1} is recommended for maize under grain amaranth or soybean rotation. This coincides with Kamanga, (2013), who reported that the *Striga* population decreased significantly with higher rates of N.
- Soybean-maize crop rotation had the highest economic benefits at all levels of N. Grain amaranth-maize rotations at all levels of N resulted to high economic benefits than maize monocrop at all levels of N. According to K Weber, (1987), grain amaranth has the potential for improving food and nutritional security, providing diversity in food and agriculture, broadening the food base,

enhancing utilization of underdeveloped food materials, and improving the profitability of cropping systems. Grain amaranth-maize rotation without N increased net returns by Ksh.47, 209 per hectare which is a 27% increase as compared to maize mono-cropping at 0 Kgs N ha^{-1}. It is therefore economical and sustainable to farmers to include grain amaranth in crop rotation programs.

6.2. Recommendations

- Monocropping is the major farming system practised by over 90% of the farmers in western Kenya. The research results clearly indicated that crop rotation was significantly better than monocropping. It is recommended that farmers adopt crop rotation. This will assist to reduce *Striga* weed infestation in replenishing soil fertility, boost food production and income for the ever-increasing population.
- From the results, amaranth-maize rotation with N resulted in the lower population of *Striga* and higher maize yield than maize-maize rotation. Farmers should, therefore, consider including grain amaranth in their rotational programmes in efforts to control *Striga*.
- Increased rates of N in all the crop rotations in the experiment increased maize yield and reduced *Striga* population. It is recommended that the county government and other agencies in the region impact on massive campaigns to educate farmers on the need to use N fertilizer.

6.3 Way forward

- More field trials of Amaranthus lines for *Striga* suicidal germination needs to be done. Further investigation needs to be done to evaluate across a wider combination of maize and grain amaranth varieties and across different locations in western Kenya and the country at large.
- Farmers should consider venturing in grain amaranth as an alternative source of food and income while controlling *Striga* menace.

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APPENDICES

Appendix I: Analysis of variance of rotation effect of grain amaranth,soybean, maize and nitrogen fertilization on *Striga* intensity 8WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	87.66	43.83	2.40	
Crop rotation	2	1515.21	757.61	41.46	<0.001
Residual	4	73.10	18.27	0.73	
Nitrogen	8	929.96	232.49	9.29	<0.001
Nitrogen*crop rotation	8	98.49	12.31	0.49	0.85
Residual	24	600.36	25.01	1.54	
Total	134	5903.44			

Note: df= degree of freedom, ss=sum of squares, ms=mean square, F pr. =level of probability.

Appendix II: Analysis of variance of rotation effect of grain amaranth, soybean, maize and nitrogen fertilization on *Striga* intensity 12 WAP.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Blocks	2	75.75	37.87	1.15	
Crop rotation	2	2913.35	1456.67	44.39	<0.001
Residual	4	131.27	32.82	0.88	
Nitrogen	4	2817.59	704.40	18.91	<0.001
Nitrogen*crop rotation	8	115.39	14.42	0.39	0.917
Residual	24	894.09	37.25	1.56	
Total	134	10586.77			

Note: df= degree of freedom, ss=sum of squares, ms=mean square, F pr. =level of probability

Appendix III: Analysis of variance of rotation effect of grain amaranth, soybean, maize and nitrogen fertilization on *maize height at 8* WAP.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Blocks	2	524.01	262.01	0.67	
Crop rotation	2	4354.24	2177.12	5.55	0.007
Residual	4	1568.74	392.19	3.65	
Nitrogen	4	22021.51	5505.38	51.25	<0.001
Nitrogen*crop rotation	8	2251.24	318.91	2.97	0.018
Residual	24	2577.91	107.41	1.09	
Total	134	43666.33			

Note: df= degree of freedom, ss=sum of squares, ms=mean square, F pr. =level of probability

Appendix IV: Analysis of variance of rotation effect of grain amaranth, soybean, maize and nitrogen fertilization on *maize height at* 12 WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	34430.02	37.87	1.15	
Crop rotation	2	2913.35	1456.67	44.39	0.002
Residual	4	131.27	32.82	0.88	
Nitrogen	4	2817.59	704.40	18.91	<0.001
Nitrogen*crop rotation	8	115.39	14.42	0.39	0.917
Residual	24	894.09	37.25	1.56	
Total	134	10586.77			

Note: df= degree of freedom, ss=sum of squares, ms=mean square, F pr. =level of probability

Appendix V: Analysis of variance of rotation effect of grain amaranth, soybean, maize and nitrogen fertilization on *yield of maize*.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	1.6478	0.88239	3.93	
Crop rotation	2	39.1341	19.5670	93.28	<0.001
Residual	4	0.8391	0.2098	1.14	
Nitrogen	4	84.3116	21.0779	114.11	<0.001
Nitrogen*crop rotation	8	1.6213	0.2027	1.10	0.399
Residual	24	4.4333	0.1847	0.81	
Total	134	155.0437			

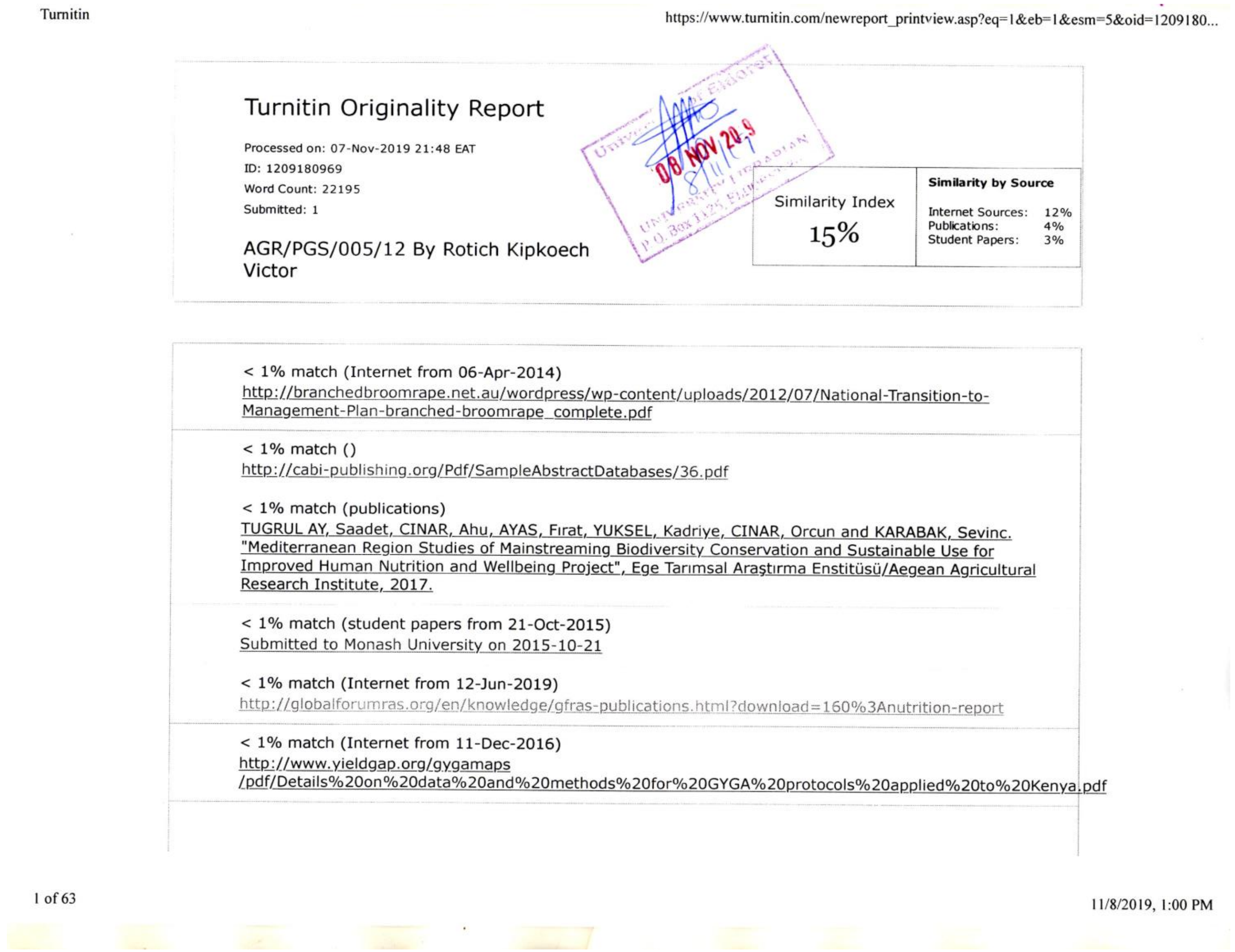
Note: df= degree of freedom, ss=sum of squares, ms=mean square, F pr. =level of probability

Appendix VI: Analysis of variance of rotation effect of grain amaranth, soybean, maize and nitrogen fertilization on *maize stover weight.*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	1.6196	0.8098	5.04	
Crop rotation	2	70.3217	35.1608	218.85	<0.001
Residual	4	0.6426	0.1607	0.57	
Nitrogen	4	250.9116	62.7279	221.46	<0.001
Nitrogen*crop rotation	8	17.7880	2.2235	1.70	<0.001
Residual	24	6.7979	0.2832	1.56	
Total	134	389.5557			

Note: df= degree of freedom, ss=sum of squares, ms=mean square, F pr. =level of probability

APPENDIX VII : Similarity Index/Anti-Plagiarism Report



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Similarity Index	Similarity by Source	
15%	Internet Sources:	12%
	Publications:	4%
	Student Papers:	3%

< 1% match (Internet from 06-Apr-2014)
http://branchedbroomrape.net.au/wordpress/wp-content/uploads/2012/07/National-Transition-to-Management-Plan-branched-broomrape_complete.pdf

< 1% match ()
http://cabi-publishing.org/Pdf/SampleAbstractDatabases/36.pdf

< 1% match (publications)
TUGRUL AY, Saadet, CINAR, Ahu, AYAS, Fırat, YUKSEL, Kadriye, CINAR, Orcun and KARABAK, Sevinc. "Mediterranean Region Studies of Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Human Nutrition and Wellbeing Project", Ege Tarımsal Araştırma Enstitüsü/Aegean Agricultural Research Institute, 2017.

< 1% match (student papers from 21-Oct-2015)
Submitted to Monash University on 2015-10-21

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http://globalforumras.org/en/knowledge/gfras-publications.html?download=160%3Anutrition-report

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http://www.yieldgap.org/gygamaps/pdf/Details%20on%20data%20and%20methods%20for%20GYGA%20protocols%20applied%20to%20Kenya.pdf

1 of 63 11/8/2019, 1:00 PM