EFFECTS OF NITROGEN FERTILIZER AND HERBICIDE COATED MAIZE SEED IN MANAGEMENT OF *STRIGA HERMONTHICA* IN WESTERN KENYA

BY

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DECLARATION

Declaration by the candidate.

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or University of Eldoret.

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ABSTRACT

Striga hermonthica (witch weed) infestation and low soil fertility are two major constraints to maize production in western Kenya. The low inherent soil fertility and poor crop management practices result in subsequent *Striga* infestation thereby reducing maize productivity and driving several rural households into extreme poverty. Because of this, maize production averages 0.2 to 0.5 tons per hectare which is below the national potential average of 6 tons per hectare. Farmers in the region respond to the problem through various available *Striga* control methods developed by researchers. For instance, inorganic N fertilizers, resistant/tolerant maize varieties, hand pulling of witch weed, irrigation and use of cover crops have been tried by farmers. Each of these has been done on its own, not in combination with others, no significant effect on witch weed reported. The combination of two or more of these methods can bring a significant reduction of the weed. The main objective of the study was to evaluate the effect of two maize varieties (IR maize and DH04) in combination with inorganic N fertilizer in reducing *Striga* infestation and seed bank, improving soil fertility and increasing maize yields. Field experiments were conducted in Bondo, Siaya and Vihiga districts, western Kenya for two consecutive seasons (short rainy season, 2011 and long rainy season, 2012). Treatments included two maize varieties (IR maize and dry land hybrid maize (DH04)), two inorganic N fertilizer rates (0 Kg N ha^{-1} and 60 Kg N ha^{-1}) and two soil fertility status, (low and high soil fertility status). The treatments were arranged in a split-split plot structure in a complete randomized block design (CRBD) replicated 30 times (using farms as replicates). soil fertility status and Maize varieties were assigned to the main and sub plot respectively while N fertilizer rates was assigned to sub-sub plots. Fertilizer N was applied at a rate of 60 kg N ha^{-1} in split application of 25 kg ha^{-1} at planting and 35 kg ha^{-1} at 6 weeks after planting. All treatments received basal phosphorus (P) and potassium (K) at rates of 30 kg ha^{-1}. Results showed that the fertilized plots had significantly ($P \leq 0.05$) higher percentage nitrogen over the unfertilized plots in all the sites. In Bondo, Siaya and Vihiga, the percentage increase in total N was by 17%, 13% and 21%, respectively. The fertilized plots with IR maize significantly ($P \leq 0.05$) reduced *Striga* emergence by 38%, 20% and 29% in Bondo, Siaya and Vihiga, respectively. *Striga* emergence was significantly ($P \leq 0.05$) lower in the high fertility soils compared to low fertility soils. Addition of nitrogen fertilizer at 60 kg N ha^{-1} significantly ($p<0.05$) increased maize grain yield relative to control in all the sites. IR maize in the fertilized plots significantly ($P \leq 0.05$) reduced *Striga* seed bank density by more than 50% in all the sites across the rainy seasons. Combining resistant/tolerant maize varieties with N fertilizers is an effective strategy of controlling *Striga* and increasing maize yields in low fertility soils of western Kenya. It is recommended that farmers in western Kenya should practice combinations of IR maize with 60 kg ha^{-1} of N-fertilizer to reduce *Striga* density and increase maize grain yield.

DEDICATION

To my wife Rehema Maritim, who natured me with love and encouragement during the entire study. To my parents, Maritim Kalya and Rebecca Kalya, who provided moral support and had the wisdom to send me to school. May God bless you abundantly.

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LIST OF ABBREVIATIONS

CAN	Calcium ammonium nitrate
CIMMYT	International Maize and Wheat Improvement Centre
CRBD	Complete randomized block design
DH	Dry land hybrid
Fig	Figure

FYM	Farm yard manure
H	Hybrid
IITA	International Institute of Tropical Agriculture
IR	Imazapyr resistant
LR	Long rainy season
ML	Milliliters
N	Nitrogen
P	Phosphorus
RPM	Revolutions per minute
SHF	Small holder farmers
SLU	Swedish University of Agricultural Sciences
SSA	Sub Saharan Africa
SR	Short rainy season
WAP	Weeks after planting
WS	Western seed

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CHAPTER 1

INTRODUCTION

1.0 Background.

Maize is the most important crop/staple food for over 80% of small holder farmers (SHF) in Sub Saharan Africa (SSA). The average yield in Kenya is below 2 tons per hectare while the potential yield is 6 tons per hectare (Kim *et al.*, 1997). In western Kenya, maize production is below 0.5 tons per hectare (Ayaga, 2003). The low maize yields is associated with several constraints, among them are low soil fertility (Okalebo *et a.,l* 1997) and *Striga hermonthica* (also known as witch weed) infestation (Ransom 1996) which have caused significant yield loss ranging from 30 to 70% depending on the agro-ecological zones (Vanlauwe *et al.,* 2008). This thesis focused on low soil fertility and *Striga hermonthica* infestation as the major constraints to maize production in western Kenya. Wherever possible, the shorthand name *"Striga"* is used instead of the full species name *Striga hermonthica*.

1.1. Declining soil fertility.

In western Kenya, declining soil fertility is a result of poor soil and crop management practices. SHFs usually cultivate their land without adequate supply of inputs such as inorganic and/or organic fertilizers (Anderson and Ingram 1996). The low inherent fertility status of the soils, their low buffering capacity and farmer's trend not to invest in soil fertility management strategies, have resulted in low fertility soils that are continually declining and are hardly able to sustain reasonable maize yields, with nitrogen (N) and phosphorus (P) being the major limiting nutrients (Okalebo *et al.*, 1997).

However, application of fertilizer can increase the availability of soil nutrients particularly N and therefore creates favorable conditions for growth of healthy maize plants.

1.2. *Striga* incidence.

One of the most detrimental parasitic weed in SSA is the genus *Striga* (Scrophulariaceae). The main species of *Striga* in the region are *Striga hermonthica* (Del.) Benth, *Striga asiatica* (L.) Kuntze and *Striga forbesii*. Of the three species, *S. hermonthica* (Del.) Benth is the most prevailing in the Lake Victoria Basin of Kenya, Uganda, and Tanzania (Fig 1). This species is relatively widespread in terms of scope of geographical coverage and is found across a wide range of natural environments within Uganda and Kenya (Oswald and Ransom, 2001). The parasitic witch weed penetrates and attaches itself to the roots of host (maize) plants. Once attached to the host plant, *Striga* deprives the host of nutrients and water, reducing yields, and often destroying the plant. In SSA, about 50 million hectares of cropped area are *Striga* infested, creating economic losses projected at $7 billion on an annual basis (Khan *et al.,* 2006). The witch weed hinders cereal production and accounts for more than 50% of yield losses in SSA region (Lagoke *et al*, 1991; Parker, 1991) which affects the livelihood of about 300 million people (Ransom ,1996).

Striga will only germinate in response to specific chemical stimulants (i.e. plant root exudates) received from the host plant. Although maize and sorghum are most often associated with *Striga*, other crops such as millet, upland rice, and even sugar cane can also serve as a host for *Striga* (Joel, 2000). *Striga* also exerts phytotoxic effect on its host causing severe stunting and deprives the host short of nutrients, water and eventually reducing yields (Ransom *et al.*, 1996). As a result, plant performance is rigorously cleaned out by *Striga* with a large reduction in host plant height, biomass, and ultimately grain yield (Parker and Riches, 1993; Gurney *et al.*, 1999). *Striga* is a persistent problem and once an initial infestation has been established, *Striga* can spread rapidly to other fields and nearest farms. *Striga* seeds are small, and a single plant can produce more than ten thousands seeds. Many times the seeds are transmitted unintentionally by farmers traveling across fields and through livestock grazing. The livestock, on their feet can spread soil containing *Striga* seeds as they are grazing. *Striga* seeds can become dormant in the soil for more than 10 years (IITA, 1979).

Plate.1: *Striga hermonthica* in infested maize field in Bondo, western Kenya. (Source: Author, 2014)

1.3. Problem statement.

In Kenya, *Striga* infestation is mainly severe in Nyanza and western provinces (western Kenya region). *Striga* infests over 210,000 ha of farm land, thereby reducing farm productivity and driving several rural households into extreme poverty. In maize fields that are not infested by *Striga*, farmers may possibly expect an average maize yield of over 1.5 tons per hectare. However only 0.3 tons per hectare is obtained in situation where there is high *Striga* density in the region. *Striga* infestation is majorly related to continuous mono-cropping, low soil fertility and increased land use intensification, among other variables. The Low soil fertility, particularly nitrogen deficiency, is the main cause for the increase in *Striga* incidence in Kenya's Nyanza and western provinces which has caused considerable yield losses in the region. Several *Striga* control options have been introduced but with no or little impact and the problem continues to persist. Most of the *Striga* control options do not perform well on their own hence need for an integrated approach. For instance, the Imazapyr herbicide resistant (IR) maize is known to reduce *Striga* incidence but little information exists on how an integrated method involving IR maize and N fertilizer affects the *Striga* infestation, seed bank and soil chemical properties. Therefore research needs to be conducted in areas that can reduce *Striga* infestation, *Striga* seed bank in the soil and improve soil fertility status.

1.4. Justification.

More than 50% of the population in Western Kenya depends on maize for daily consumption. The consumption rate has been estimated to be 120 kg per adult annually (Berner *et al.*, 1996). The maize production in the region is below the national average production level which is not enough to sustain the current population. The declining soil fertility and *Striga* incidence are among the major causes of food insecurity in the region and thus leading to low maize production driving several household into extreme poverty. In most studies the effect of IR maize and N fertilizer in controlling *Striga* incidence have been determined in isolation and this has not been effective hence there is need to address and come up with an integrated approach to soil fertility management and *Striga* control that will increase maize yield.

1.5. Objectives.

1.5.0. Main.

To evaluate the effect of two maize varieties (IR maize and DH04) in combination with different rates of nitrogen fertilizer on *Striga* weed management, soil fertility improvement and maize yields in western Kenya.

1.5.1. Specific.

To determine:

1. The changes in soil nitrogen and maize yields in response to N-fertilizer under *Striga* infestation.
2. Varietal and nitrogen effect on *Striga* infestation and seed bank reduction.
3. Soil fertility status effect on *Striga* infestation and seed bank reduction.

1.6. Hypotheses.

Null hypothesis (Ho)

1. IR maize will not have any effect in reducing *Striga* emergence and seed bank in the soil.
2. Application of nitrogen fertilizer will not improve soil chemical status, maize yields and not reduce *Striga* emergence and seed bank in the soil.

3. Soil fertility status will not have any significant effect in *Striga* emergence and *Striga* seed bank in the soil.

CHAPTER 2

LITERATURE REVIEW

2.0. Origin of *Striga*.

The genus *Striga*, family orobanchacecae, contains about 41species that are found in the continent of Africa and parts of Asia. The most dominant species in SSA is *Striga hermonthica* (Del.) Benth which originated in the Nuba mountains of the Sudan and in parts of Ethiopia (Ransom 1996). It is most common on heavy soils, particularly in the densely populated parts of the Lake Victoria region of Western Kenya (Kiriro, 1991; Frost, 1994). It is also widespread in eastern and northern Uganda on sorghum and finger millet (Oryokot,1994; Ebiyau *et al*., 2000). *Striga asiatica* is found in the Coast Province and seriously damaged upland rice (Kiriro, 1991). Hassan and Ransom (1998) confirmed that *Striga* incidence in maize is increasing in the moist transitional zone in Kenya with a total affected area of about 300,000-500,000 ha.

2.1. Life cycle of *Striga hermonthica.*

Life cycles and symptoms of *Striga* parasitism are generally similar, in spite of of the host-parasite combination, although there are some minor variations. Seeds are the sole source of inoculums. They are produced in large quantity (roughly 10,000 to 100,000 or more per plant) (Pieterse and Pesch, 1983). The seeds weigh approximately 10^{-5} g each and are about 200 microns wide by 300 microns long.

After dispersal, seeds may remain dormant for several months; during this time, seeds will not germinate even if conditions are ideal. This period is termed after-ripening (Vallance, 1950), and it may be an evolutionary adaptation to prevent germination during the last rains of the season, when there are no hosts around. Studies have indicated that the span of the after-ripening period is diverse for different *Striga* species and for seed samples collected from different geographical areas (Van Mele, *et al.*, 1992). It may be anywhere from a few days to 2 years.

After the *after-ripening* period, seeds will germinate only under conditions of favorable moisture and temperature (free moisture adequate for seed inhibition (Van Mele *et al*., 1992) and at temperatures between 20 and 33 ^{o}C (Bebawi *et al*., 1984) and only in the presence of a germination stimulant, usually exuded from host plant roots.

2.2. *Striga* seeds dispersal.

Striga hermonthica seed dispersal and spread are dependent on the particular cropping system and that control may be affected by management of that system. Although *Striga* seeds are very small, they are not efficiently dispersed by wind (Berner *et al*., 1994). This is fortunate because efficient and widespread dissemination of these parasites by wind would be virtually out of control; control strategies would then be difficult to devise. Report from research done at IITA indicated that man is the primary disseminating agent of *Striga* seeds. Man moves these seeds through the livestock that he manages and through the soil. The first step in reducing damage from *Striga* is to prevent further movement of livestock into fields. This implies restriction of animal movement from *Striga*-infested areas to *Striga*-free areas or areas under *Striga* control management. Because many farmers store crop seeds from season to season, it is important that they prevent these seeds from becoming contaminated with soil containing *Striga* (Cardwell, *et al*., 1991). The best means of doing this is to move harvested plants to *Striga*-free areas before laying them on the ground to dry. An alternative would be the yearly purchase of clean crop seeds from reputable seed companies. However the spread is severe in monocropping systems of farming and subsequent increases in livestock populations. Management of farming systems, therefore, must include rotations with crops that are not hosts of *Striga* if sustainable productivity is to be maintained. The most desirable rotational crops are legumes which can reduce *Striga* populations and improve soil fertility (Hassan and Ransom, 1998).

2.3. *Striga* infestation in maize fields.

The magnitude of *Striga* severity is higher in counties in western and Nyanza than in other parts of Kenya. Over 93% of the area infested in Kenya is in the low, medium and high infestation categories, accounting for a total of 319,441 ha (De Groote *et al.*, 2007). Of the total infested area, 114,597 hectares (33.6%) are severely infested with *Striga*. Putting this in perspective, the area under severe *Striga* infestation represents approximately 20% of all crop losses in Kenya, including 35,000 metric tons of maize (De Groote *et al*., 2007).

2.4. Yield and economic loss due to *Striga.*

Most of the *Striga* losses are found in the Lake Victoria basin where *Striga* infestation is severe. This has been reported in Nyanza and Western counties in Kenya, where reported maize losses from *Striga* damage reach as high as 2.8 tons per ha in some locations. In Kenya, the average losses for maize are on average 1.2 tons per hectare (De Groote, 2007).

A total of 308,520 metric tons of maize are lost in an average year in Kenya due to *Striga*. This represents 12.3% of the approximately 2.5 million metric tons of maize that Kenya produces annually. On average, 39.6 kg per annum of maize is lost on a per capita basis in Kenya, which amounts to about 20% of a typical person’s annual food requirements (De Groote, 2007).

Macopiyo *et al.,* (2010) reported that *Striga* incur significant losses on cropping systems in western Kenya, while available *Striga* control strategies offer commensurate potential for mitigating damage and enhancing productivity in maize, millet, sorghum, and upland rice. Significant yield increases can be particularly achieved through the use of IR maize in combination with nitrogen fertilizer (Mbwaga, 2003).

2.5. Contribution of *Striga* occurrence to rural poverty.

The problems of *Striga*-infested fields have been aggravated over the years as a result of the use of *Striga*-infested maize seeds infested with soils containing *Striga*, continuous cultivation of *Striga* susceptible varieties, uncontrolled grazing (livestock spread *Striga* seeds in soil when they move from *Striga* infested field to *Striga* free fields) and non-adoption of integrated *Striga* management strategies (Kanampiu *et al.*, 2003).

Striga has a negative effect on the rural poor, with infestation more prevalent in areas with higher rates of poverty. In the heavily infested *Striga* zones, rural poverty rates often exceed 70% or more (Hassan and Ransom 1998). Where infestation is lighter, poverty rates are often 20% or less. Consequently, introducing *Striga* control measures would also have indirect differential impacts on reduction of rural poverty. Although it is the more impoverished areas that are most severely affected by *Striga* damage, the rural poor are also the group that would benefit the most from introducing *Striga* control measures. A majority of the impacts could be concentrated in the areas where rural poverty rates exceed 70% (De Groote, 2007).

2.6. Cultural and mechanical control for *Striga.*

2.6.0. Push-pull (habitat management).

In push-pull technology, Napier grass is planted around a field planted with cereal and desmodium is planted between the rows of the cereal crop. The smell, or production of semiochemicals, by desmodium ‘pushes’ the stem borer moths away from the maize. In addition, the desmodium produce exudates that induces germination of the *Striga* seedlings but does not support their growth. However, the *Striga* seedlings are unable to attach to the desmodium plant and the *Striga* seeds die through a process called “suicidal germination”. The stem borers that are pushed away from the desmodium are pulled by volatiles that are produced by the Napier grass, where they lay their eggs, yet these eggs cannot develop into larvae as napier grass produces sticky glue that traps and kills the larvae. Thus the terms “push-pull” and “suicidal germination” (Kanampiu *et al.,* 2003).

2.6.1. Cereal-legume intercropping.

Promiscuous soybean (*Glycine max*) is another legume that has exhibited traits of incurring suicidal germination of *Striga*, yet there is a large difference between different soybean varieties (Odhiambo *et al*., 2009). Soybean also has excellent soil fertility enhancing qualities (N-fixation) (Vanlauwe 2002), through simultaneous production of high amounts of biomass and grain yield in so called dual purpose varieties. Intercropping maize with soybean therefore could results in reduction of *Striga* seed bank and increases in maize yield.

However, studies in Kenya indicate that intercropping with cowpeas between rows of maize significantly reduced *Striga* numbers when compared to within 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). The intercrop yield can under favourable conditions compensate for the loss of cereal in economic terms, but the practice may not be acceptable to farmers already suffering reduced cereal yield due to *Striga*. There is therefore a need to conduct research to explain the effect of intercropping on both the above ground and the below ground development of both the host crop and the parasite.

2.6.2. Crop rotation systems.

Crop rotation of infested land with non-susceptible crops or fallowing can reduce *Striga* infestation. Rotation with non-host crops interrupts further production of *Striga* seed and leads to decline in the seed population in the soil. However, the practical limitations of this technique are the more than three years required for rotation. The choice of rotational crop should therefore be based on its suitability to the local conditions and only secondarily on its potential as a trap crop (Parker and Riches, 1993).

The use of trap and catch crops that induce the germination of *Striga* but are not themselves parasitised is currently one of the best methods to control agricultural root parasites. Roots of cowpea and soya bean stimulate the germination of *S. hermonthica*.

2.6.3. Time of planting.

The degree of infestation of the host plant by *Striga* can be affected by the planting date. Field trials in Kenya indicated that planting date had no consistent effect on mid season *Striga* counts and parasitism of maize or sorghum (Ransom and Osoro, 1991). However, in a bimodal rainfall pattern, *Striga* is normally worst in the crops sown in the early rains. Although early planting did not significantly reduce *Striga* emergence, the potential crop yield of the season was realised (Ransom 1996).

2.6.4. *Striga* tolerance/resistance cereal varieties.

Screening for resistance to *Striga* in maize was initiated at the International Institute of Tropical Agriculture (IITA) in 1982. Considerable progress has been achieved at IITA by the International Maize and Wheat Improvement Centre (CIMMYT) in developing open pollinated varieties, inbred lines and hybrids that have both reduced host plant damage symptoms (tolerance) and reduced parasite emergence under artificial infestation with *S. hermonthica* (Kling *et al*., 2000). Resistant varieties have been developed with adaptation to the lowland and mid-altitude ecologies, with a range of 90 to 120 days to maturity, grain colour and grain texture characteristics. The best varieties have been extended to farmers through the efforts of the regional maize and *Striga* networks and several collaborative projects (Kling *et al*., 2000). In Kenya, Ransom and Odhiambo (1992) investigated the growth and development of *S. hermonthica* on sorghum cultivars Seredo, Serena and maize cv H511, H512, H622, H632 and Katumani Composite. Maize was more sensitive to *S. hermonthica* parasitism than sorghum. Katumani Composite had less *Striga* and more yield than H511 and H622 in a heavily infested field. Further work under field conditions showed that fewer roots were present in the topsoil for Katumani, confirming that avoidance rather than resistance was the mechanism associated with reduced *Striga* attack (Baltus *et al*., 1994). Odhiambo and Ransom (1995) evaluated 15 genotypes of maize with a wide range in days to maturity for the level of *S. hermonthica* parasitism. The results indicated that in some seasons, early maturing genotypes can reduce *Striga* attack in heavily infested areas and yield more than late maturing genotypes. Odongo and Abayo (1999) tested seven maize varieties in western Kenya and two varieties (Nyamula and KTSP94) were found to be tolerant to *Striga* infestation.

2.6.5. Nitrogen fertilizer.

Fertilizers is one of the essential inputs used for maintaining and increasing the soil fertility level in intensive agricultural systems and primarily supply the crop with essential nutrients or facilitate uptake of a particular nutrient (Vanlauwe *et al*., 2002).

The use of nitrogen to suppress *Striga* has been demonstrated in the East and Central African highlands (Esilaba and Ransom, 1997; Esilaba *et al*., 2000; Gacheru and Rao, 2001). Mumera (1983) recorded a 64% reduction in *S. hermonthica* emergence in maize using 39 kg N ha^{-1} as calcium ammonium nitrate (CAN). Studies in Western Kenya show that CAN at 0-140 kg N per hectare had no significant effect on maize yield but reduced *Striga* populations. Increases in maize yield after application of 20 tons per hectare and 300 kg N per hectare as ammonium sulphate nitrate were also reported in Kenya. Farmyard manure trials indicated that 100 tons per hectare reduced *Striga* counts and increased maize yield. Mumera and Below (1993) found that although *Striga* infection generally declined with increasing N availability, the impact was partially dependent on the severity of infestation. The results of field trials with basal application of N fertiliser over many years in many countries have not been consistent in terms of either crop yield or *Striga* numbers. From the many studies conducted on the effect of fertiliser on *Striga*, it may be concluded that under certain conditions, N may reduce *Striga* infestation. However, under nutrient depleted soil conditions, fertiliser may stimulate infestation. This increase could be due to an increase in the biomass of host roots enabling more parasite seeds to germinate. The difference in results from various N fertiliser studies may be due to differences among host plants, chemical interactions, micro-organisms, soil texture and moisture. Other factors may include the source of fertilizer N (Mumera and Below, 1993), the time of its availability in relation to crop growth or even transfer of ammonium to nitrate. Soil fertility has been found to be significantly linked to *Striga* infestation (Vanlauwe *et al*., 2008). In nutrient poor soils, *Striga* typically flourishes. Conversely, where soils are managed with adequate quantities of nutrients, *Striga* infestations are seldom encountered (Vanlauwe *et al*., 2008).

2.7. Biological control methods.

Few systematic studies of individual natural enemies of *Striga* and their influence on the population of host plants have been conducted. The genus of greatest interest for biological control is *Smicronyx* of which several species are highly specific to *Striga*. Some fungal pathogens have been isolated from emerged *Striga* plants of which *Fusarium nygamai* and *F. semitectum* var. *majus* reduce germination and/or kill *S. hermonthica*. However, further studies under field conditions need to be conducted (Abayo *et al.*, 1996).

2.8. Chemical control methods.

2.8.0. Germination stimulants.

Certain chemicals such as ethylene, ethephon, strigol and strigol analogues can induce germination of *Striga* seeds in the absence of a suitable host and therefore reduce seed reserves in the soil (Esilaba and Ransom, 1997). Ethylene can reduce *S. asiatica*, however, *S. hermonthica* may not be well controlled by ethylene under field conditions in eastern Africa (Ransom and Njoroge, 1991).

2.8.1. Herbicides.

Among the chemicals investigated for efficacy in controlling *Striga* is Dicamba, which can provide early season control but has not proven to be consistently cost-effective (Odhiambo and Ransom, 1993). However, Imazapyr gives early season *Striga* control in specific varieties with increased maize yields and may offer complete control at an affordable cost for subsistence farmers (Abayo *et al*., 1996 and Abayo *et al*.,1998). On-farm trials in Kenya and Tanzania indicate that seed dressing with Imazapyr and

Pyrithiobac offers good *Striga* control and increased maize yields (Kanampiu *et al.*, 2004). Many herbicides are useful in preventing the build-up of *Striga* seeds in the soil but may not prevent the damage done by *Striga* plants before emergence.

2.8.2. Integrated control of *Striga.*

Several integrated techniques for the control of *Striga* have been developed and tested. Mumera (1983) investigated the efficacy of 3 herbicides with N fertilizer on maize and sorghum cultivars. Several on-farm trials have been conducted in western Kenya to compare proposed integrated *Striga* management practices with farmer practices. These trials involved the use of FYM at 10 t ha^{-1}), fertilizer (50 kg ha^{-1} and 50 kg P_2O_5 ha^{-1}, normal hand-weeding, and 3 maize varieties (hybrid 511, synthetic Tzi 1 and a local variety). Results showed that long-term repeated application of appropriate packages was required to confirm their cumulative benefit. Odhiambo and Ransom (1994) evaluated long-term effects of trap cropping (cowpea and cotton and other maize management systems (fertilizer, hand-pulling and ethylene) on the restoration of land infested with *S. hermonthica* for 4 seasons. Trap crops were not effective in reducing numbers while ethylene reduced *Striga* infestation but did not increase maize yields as the soil fertility was low. Hand pulling *Striga* before seed set was as effective as trap cropping. However, application of fertilizer to maize and repeated hand pulling led to the lowest infestation and the highest maize yield (Odhiambo and Ransom, 1994). Odhiambo and Ransom, (1994) found that incorporation of stover combined with fertilizer and hand-weeding had the highest yield. They recommended that maintenance of soil fertility (fertilizer and crop residues) and the removal of *Striga* before seed set would restore the productivity of lands infested with *Striga*.

CHAPTER 3

MATERIALS AND METHODS

3.0. Study sites.

3.0.0. Site selection and description.

The study was conducted in three locations in western Kenya (Table 1). Ten (10) farms were selected from each of the three sites that made a total of 30 farms. Farmers were asked to show which fields they considered to have high soil fertility status (low *Striga* density) and low soil fertility status (high *Striga* density).

The major soil types found in Bondo, Siaya and Vihiga are ferralsols and acrisols (Table 1) Mwaura, (2003). The region has a bimodal rainfall distribution pattern (Jaetzold and Schmidt, 1983) with long rainy season starting from March to July and short rainy season starting from September to December (Jama *et al*., 1997). Atmospheric temperatures in Nyanza and western provinces (Lake Victoria basin) region are higher than in other places thus favors faster crop growth; therefore crops are grown in two seasons per year. In the region, maize yields among the SHF are often less than 0.5tons per hectare per year and the yields are on the decline even among the large-scale farmers (Ayaga, 2003; Sanchez *et al*., 1997). Most SHF cannot produce enough maize for consumption and must therefore purchase from the market throughout the year or endure hunger periods (Sanchez *et al*., 1997). The cause of declining maize yields has been identified as *Striga* incidence and soil fertility depletion particularly P and N (Okalebo *et al*., 1997; Ransom, 1996).

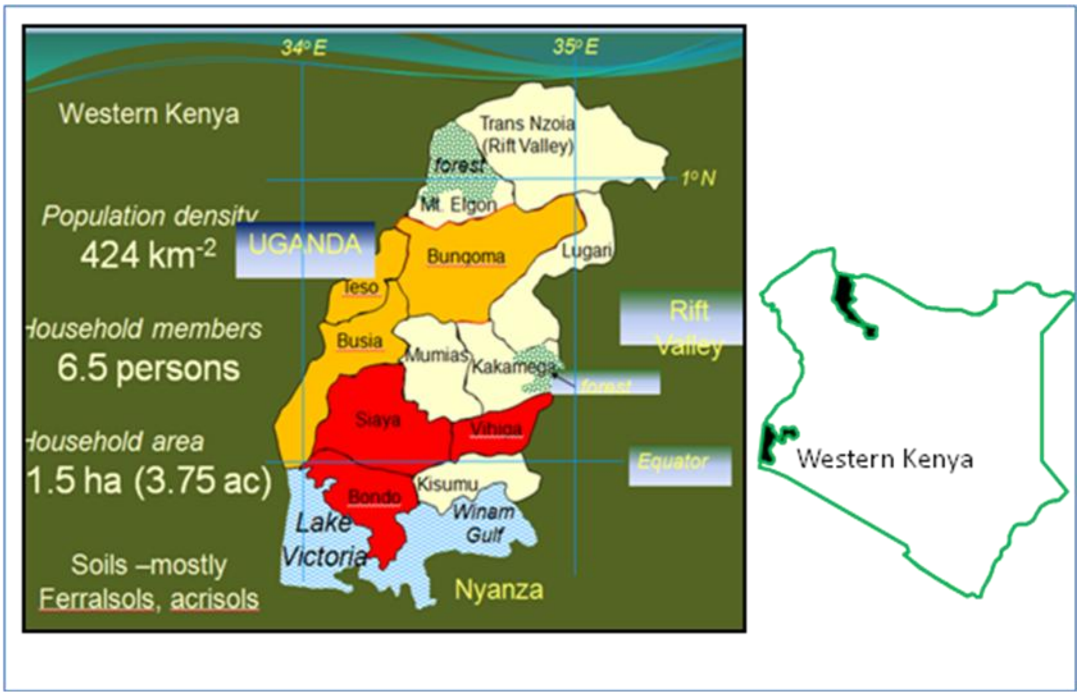


Plate.2: Experimental sites; Bondo, Siaya and Vihiga are indicated in red color.

(Source: Mwaura, 2003).

Table 1: Location, climatic and soil types of the experimental sites.

No.	District	Specific Location	Latitude and Longitude	Elevation (m) above sea level	Mean annual Rainfall (mm)	Soil Type
1	Vihiga	Bukulunya	0^{o}10’N, 34^{0} 30’E	1463-1456[2]	1600 -1808[2]	Chromic Ferralsols[1]
2	Siaya	Nyabeda	0^{o}15’N,35^{o} 0’E	1330-1265[2]	900 -1400[2]	Orthic Ferralsols[2]
3	Bondo	Ajigo	0^{o}34'N,19^{o}14’E	1331-1366[2]	450 - 1200[2]	Acrisols[1]

(Source: [1]Mwaura, 2003; [2] Jaetzold and Schmidt, 1983).

3.1. Crop history of the experimental sites.

3.1.0. Imazapyr Resistant (IR) maize (WS 303).

The herbicide-resistant (IR), maize is resistant to the herbicides Imazapyr, a systemic herbicide which is believed to kill any *Striga* weeds that attach to the maize plant. The IR maize technology applies the herbicide in an innovative manner, by coating the IR maize seeds with herbicide. The IR seed-coat technology thus combines herbicide resistance in maize varieties with low dose application of systemic herbicide. The maize variety WS303 is resistant to the herbicide unlike other varieties, which when coated with the herbicide fail to germinate. The variety performs well within altitudinal range of 500-1500 m above sea level and requires 700-1800 mm of rainfall. The variety can yield up to more than four tons per hectare.

3.1.1. Maize variety DH04.

DH04 is an open pollinated hybrid variety produced by Western Seed Company which is fairly tall and produces medium cobs. It is a drought tolerant variety flowering within 60-65 days and maturing within 90-120 days. The variety performs well within altitudinal range of 900-1500 m above sea level and is a variety for marginal rainfall areas. The variety requires 250-500mm of rain and is tolerant to Maize Streak Virus. Despite its susceptibility to *Striga,* the variety can grows faster and is believed to reach maturity before *Striga* emergence and attachment to its roots. When the variety escapes the initial stage of *Striga,* it can yield up to more than 3 tons per hectare. It is mostly grown by farmers in western Kenya.

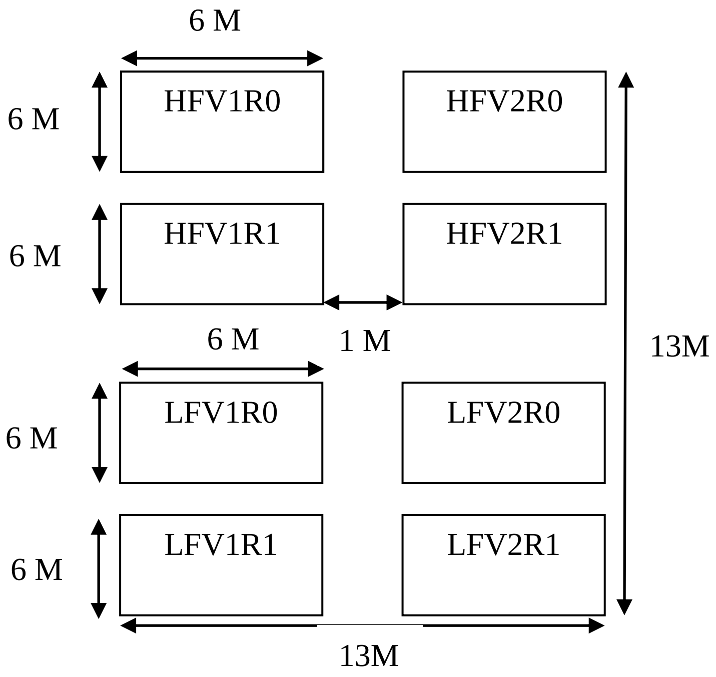
3.2. Experimental design and Treatment allocation.

Treatments included 2 maize varieties; dry land hybrid maize (DH04) and Imazapyr herbicide resistant (IR) maize (WS303), 2 rates of inorganic N urea (45:0:0): 0 and 60 kg N ha^{-1} applied in split application of 25 kg N ha^{-1} at planting and 35 kg N/ha top dressed six WAP and 2 levels of soil fertility status as indicated by farmers; High soil fertility status (low *Striga* density) and low soil fertility status (high *Striga* density). The treatments were arranged in a split-split structure in a randomized complete block design (RCBD) with high and low soil fertility levels assigned to the main plots, maize varieties assigned to the sub plot and inorganic N rates assigned to the sub-sub plots, replicated 30 times (farms were used as replicates).

Each main plot measuring 13 by 13 meters was then subdivided into four subplots of dimensions 6 by 6 meters with 1 meter path (Table 2). After that, soil samples were collected and field trials were then conducted in these fields at the onset of the short rainy season, 2011(SR2011) and continued throughout the long rainy season of 2012 (LR2012).

All the treatments received basal P and K at rates of 30 kg $P_{/}$ha and 60 kg K/ha respectively (FURP, 1994) applied as triple superphosphate (TSP) and muriate of potash (MOP) respectively. Maize was planted at a spacing of 75 cm between the rows and 25 cm within the rows (53,333 crops per ha).The fertilizer was applied along the furrows, covered slightly with soil and maize seeds were then planted and covered with soil. This was to prevent direct contact of maize seeds with the fertilizer which might cause ‘fertilizer burn’.

Table 2: Field layout.



HF and LF are high and low fertility levels respectively. V1, V2 are DH04 and IR maize varieties respectively. R0, R1 are Urea (45:0:0) nitrogen fertilizer rates at 0 and 60 Kg N per hectare respectively.

3.3. Data collection.

3.3.0. Soil sampling.

Soil samples used for initial characterization were collected prior to onset of experiment during SR2011. With the use of a soil auger, ten (10) auger soil cores were sampled in a zigzag pattern from each subplot at the sampling depth of 0-20 cm then bulked into one composite sample. To ensure homogeneity, the composite sample was mixed thoroughly and a sub sample of approximately 1 kg soil taken and put into well labeled polythene bags and the remaining samples were returned to the respective plots. After auguring, the auger holes were covered with soil. The soils were carefully transported to the laboratory and then transferred into well labeled brown sugar bags size number 4. Initial sampling was done prior to planting in September 2011 and final sampling was done at harvest at the end of SR2011 and LR2012.

The soil samples were analyzed for soil pH in water, soil particle size, available phosphorus, soil organic carbon, soil total nitrogen and exchangeable cations (sodium, potassium, calcium and magnesium) according to Okalebo *et al.* (2002). *Striga* seed bank determination was done at Kenya Agricultural Research Institute (KARI) Kibos, CIMMYT laboratory using procedures explained by Eplee and Norris, 1990.

3.3.1. Laboratory analysis.

The samples were transferred to sugar bags size number 4 and air-dried for two weeks. Large clods were broken and passed through a 2 mm sieve. Soil particle size was analyzed by Hydrometer method (Okalebo *et al*., 2002). Hydrometer method estimates amount of silt and sand taking into consideration their differential settling velocities within a water column. The settling velocity is governed by liquid temperature, viscosity and specific gravity. Hydrometer method puts consideration Stoke's Law with the assumption that the particles are spherical, have a specific gravity of 2.65, are not affected by Brownian movement and the settling velocity is proportional to the square radius of the particle. Soil pH was determined in 1:2.5 (Soil: H_20) method (Okalebo *et al.,* 2002). Soil organic carbon was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture (Okalebo *et al*., 2002). This method considers that after complete oxidation from the heat of solution and external heating, the unused or residual $K_2Cr_2O_7$ (in oxidation) is titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$, the difference between added and residual $K_2Cr_2O_7$, gives a measure of organic C content of soil. Total nitrogen was analyzed by the colorimetric method following procedures as outlined in Okalebo *et al* 2002. Colorimetric analysis considers that phosphorus forms coloured complex with molybdate, and the absorption is measured in a colorimeter. The principle takes into account the possible loss of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic and or 4-nitrosalicylic.

The available phosphorus was determined by the Olsen Method (Okalebo *et al* 2002). The Olsen method takes into account extracting soil with 0.5 M solution of sodium bicarbonate at pH 8.5. In calcareous, alkaline or neutral soils containing calcium phosphate, the extractant decreases the concentration of Ca in solution by precipitating Ca as $CaCO_3$. The exchangeable cations (potassium, calcium, magnesium and sodium) were determined using atomic absorption spectrophotometer (ASS) method (Anderson and Ingram, 1996). ASS method is based on the absorption of radiation by atoms. The radiation corresponding with the energetic difference between base situation and excitation is absorbed. The radiation pass through the flame and absorption is proportional to the concentration of the absorbing atoms in the flame. The above analysis was done to the soils sampled prior to planting and at harvesting.

3.3.2. Extraction of *Striga* seeds from soil samples.

The techniques used for extraction of *Striga* seeds from soil are based on the methods described by Eplee and Norris (1990), but a centrifuge was used instead of a glass column for separation by flotation. The maximum sample size for the procedure is 250 g soil that has been air dried. The air-dried samples were soaked for approximately 2 hours in a small plastic bucket and stirred to form a suspension. A purpose built elutriator was used to separate and exclude particles heavier than *Striga* seeds from the suspension. The lighter fraction (including the *Striga* seeds) was washed through three sieves, with pore-diameter sizes of 710, 250 and 90 microns respectively. All material collected on the 90 micron sieve was washed with water (with a washer bottle) into 70 mL polystyrene centrifuge tubes using a small funnel. Labeled tubes were centrifuged for 4 minutes in a soil centrifuge at 1800 rpm. Water and floating particles were carefully poured onto a labeled polyester cloth observation screen. The remaining pellet was re-suspended after adding a 2.9 *M* potassium carbonate (K_2CO_3) solution with a specific gravity of 1.4 and centrifuged for 30 sec at 1500 rpm. The K_2CO_3 solution and floating particles (including *Striga* seeds) were poured on another observation screen. The centrifuging with K_2CO_3 was repeated, by adding new K_2CO_3 solution to the tube, in order to extract seeds remaining in the pellet. Prominent ridges on the seed coat surface make *Striga* seeds recognizable under the microscope. *Striga* seeds were counted on all observation screens (including the assumed unviable floating seeds from the water run) using a binocular stereo microscope with 15 and 25- magnification.

3.3.3. *Striga* emergence.

Striga plants emerged from the soil were counted in each subplot (6 by 6 m) treatment at the sixth, eighth and tenth week after maize planting (WAP). *Striga* generally starts emerging from the soil at the sixth week after maize planting and the emergence spreads out through the eight week until the tenth week where there is maximum *Striga* germination count (IITA 1979). *Striga* plants emerged were uprooted at each count phase. Cumulative counts of the total number of emerged *Striga* plants were done that gave a good relative comparison of the effectiveness of different treatments in reducing *Striga* emergence.

3.3.4. Biomass sampling (Maize cobs and stover).

At harvest, a net plot area of 20.25 m^2 (4.5 by 5 m), making a total of 6 maize rows, was harvested from each sub plot. Total number of cobs and their fresh weight thereof was recorded. A sub-sample of five (5) maize cobs was selected at random from the total cobs harvested per net plot and put into brown sugar bags. The fresh weight thereof was recorded. The sub sample maize cobs were shelled and their grain fresh weight was recorded. The dry weight was recorded after oven drying at 65^0c for 24 hours. Sub sample of 100 grains were sampled at random and their weight was recorded.

Total number of maize stovers from each net plot was recorded, tied into a bundle and its total fresh weight taken. Then a sub-sample of five (5) stovers sampled, chopped into small pieces, mixed thoroughly and a sub sample taken into brown sugar bags, its fresh weight was recorded. The stover was oven dried at temperatures of 65^0C for 24 hours and dry weight was recorded.

3.4. Data analysis.

3.4.0. Statistical analysis.

Cumulative emerged *Striga* plant counts per thirty six (36) meters square were converted to plants per hectare, *Striga* seeds extracted from the 250 g volume of soil was converted *Striga* seeds per hectare basis, results obtain from soil analysis (seed bank extraction, chemical and physical elements) and calculated yield were subjected to a two way analysis of variance (ANOVA) using mixed procedures of statistical analysis system (SAS Release 9.1) to determine any significance and differences effect of treatment at $P \leq 0.05$. Due to the large variation observed in the *Striga* seeds extracted from the soil, square root transformation using the formula ($\%\sqrt{x+0.5}$) where x is *Striga* plants per hectare was performed to stabilize the large variation (Little and Hills, 1978).

3.4.1. Statistical model.

The mathematical model used was; $Yij = \mu + Fj + Vj + Nj + VNij + VFij + \alpha ij$. Where;

Yij means any observation for which i is the treatment factor, j is the blocking factor,μ means treatment mean , Fj means soil fertility effect , Vj means variety effect , Nj means nitrogen effect , NVij means variety * nitrogen interaction , VFij means variety * soil fertility status interaction and αij means main plot error.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0. Initial soil characterization in the study sites.

The results of selected physical properties of the soils in the study sites are given in table 3. In Bondo and Vihiga sites, the high and low soil fertility status had coarse textured soils with lower sand and higher clay contents and was classified as clay. Clay particles have smaller particle sizes with reactive surfaces which are important in cation exchange and chemical stability of organic matter (Okalebo *et al.*, 2002).

In contrast, the high and low soil fertility status in Siaya site had a medium textured soil and was classified as silt clay. The importance of clay content in the stability of soil organic matter was pointed out by Okalebo *et al*., (2002).

Table 3: Particle size distribution and textural class in the study sites.

Site/region	Soil fertility status	% Clay	% Sand	% Silt	Soil textural class
Bondo	High	56.4	24.8	18.8	Clay
	Low	56.1	27.0	16.8	Clay
Siaya	High	55.6	29.9	14.7	Silt clay
	Low	53.5	32.2	14.3	Silt clay
Vihiga	High	50.9	22.6	26.3	Clay
	Low	51.9	21.9	26.3	Clay

Tables 4 and 5 give the results of selected soil chemical properties in September, 2011, before the onset of experiment. In Bondo, high soil fertility status had a pH value of between 6.5-6.7 and low soil fertility status had a pH value of 5.8-6.1(Table 4). Generally in Bondo and Vihiga sites, soil pH was high in the high than in the low soil fertility status. In siaya high soil fertility status had a pH value of 5.3 and the pH value in the low soil fertility status was 5.6. In Vihiga soils, the high and low soil fertility status had a pH value of 5.4 and 5.3 respectively.

Soils in Bondo had 2.7% and 2.0% organic carbon in the high and low soil fertility status respectively. In Siaya both the high and low soil fertility status had 1.8% soil organic carbon, while Vihiga soils had 1.5% soil organic carbon in the low and high soil fertility status. The soils in high fertility status areas had slightly lower percentage organic carbon and total nitrogen contents with slightly lower C:N ratio of 12.7 compared to a C:N ratio of 14.1 that was obtained in low fertility status soils. This was thought to be as a result of high percentage clay (>50%) and the coarse texture thus reduced organic matter stability. The C:N ratio recorded was below the lower limit (18) for quick decomposition and nutrient recycling (Okalebo *et al.*, 1997).

Table 4: Soil pH, carbon and nitrogen before the onset of the experiment in the study sites.

Location	Soil fertility status	pH	Organic C (%OC)	Total N (%N)	P (Cmolkg^{-1})
Bondo	High	6.6	2.7	0.15	3.1
	Low	6.0	2.0	0.15	2.7
Siaya	High	5.6	1.8	0.16	5.3
	Low	5.3	1.6	0.13	4.1
Vihiga	High	5.4	1.5	0.13	4.6
	Low	5.3	1.3	0.12	3.7

The exchngeable cations (sodium, potassium, calcium and magnesium) were high in the high than in the low soil fertility in Bondo and Vihiga (Table 5). In Siaya, soil potassium and sodium were low in the high than in the low soil fertility status.

Generally the exchangeable cations were high across all the sites. This was thought to be as a result of application of NPK fertilizer which the farmers had use during the past seasons.

Table 5: Concentration in Cmolkg^{-1} of exchangeable cations (sodium, potassium, calcium and magnesium) in September 2011 before onset of experiment.

Exchangeable cations levels in soils.					
Location	Soil fertility status	Na (Cmolkg^{-1})	K (Cmolkg^{-1})	Ca (Cmolkg^{-1})	Mg (Cmolkg^{-1})
Bondo	High	21.8	95.8	3.5	59.8
	Low	19.1	72.3	1.3	34.0
Siaya	High	20.3	125.5	2.7	25.4
	Low	17.5	85.8	2.1	20.6
Vihiga	High	29.1	146.9	2.8	73.8
	Low	23.3	113.2	2.7	49.7

4.1. Effects of nitrogen addition on soil chemical properties in the study sites.

4.1.0. Soil pH.

There was significant difference ($P \leq 0.05$) on pH means within the sites (Fig. 1). Bondo soils had a pH value of 6.2 and 6.6 in the fertilized and unfertilized plots, respectively. In Siaya, the fertilized soils had a pH value of 5.3 while the unfertilized soils had pH value of 5.8. Low soil fertility status significantly ($p \leq 0.05$) had lower pH values as compared to the high soil fertility status irrespective of sites (Fig. 2). The effect of nitrogen rates on soil pH in the low and high soil fertility status are given in Fig 3. Soil pH level decreased significantly ($P \leq 0.05$) with increase in nitrogen rates from 0 kg N ha^{-1} to 60 kg N ha^{-1} in both low and high soil fertility status across all the three sites. Bondo had soil pH value of 6.2 and 6.4 in the low and high soil fertility status respectively. Siaya site had lower pH values of 5.1 and 5.9 in the low and high soil fertility status respectively while in Vihiga the low and high soil fertility status had pH values of 5.2 and 5.8, respectively.The interactions between nitrogen rates, soil fertility status and sites did not differ significant ($p \leq 0.05$) (Fig. 3).

The acidifying effects in response to N rates applied were attributed to seasonal application of urea 45:0:0 fertilizer that realises hydrogen ions into soil solution through ammonification and nitrification process thus reducing the soil pH. The results indicated shows that increasing the urea N fertilizer increases soil acidity irrespective of the fertility status of the soil.

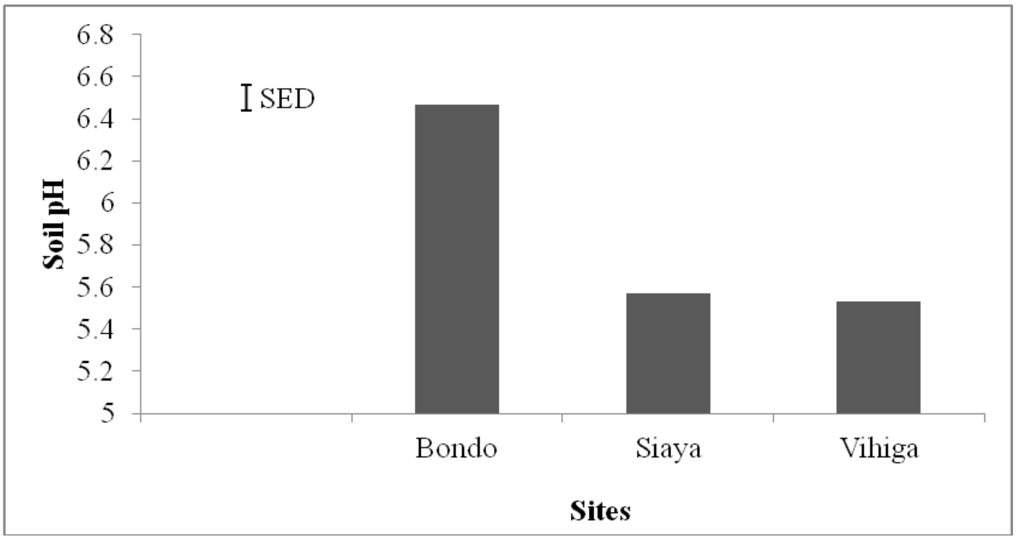


Fig.1: Soil pH in the study sites at the end of SR2011.

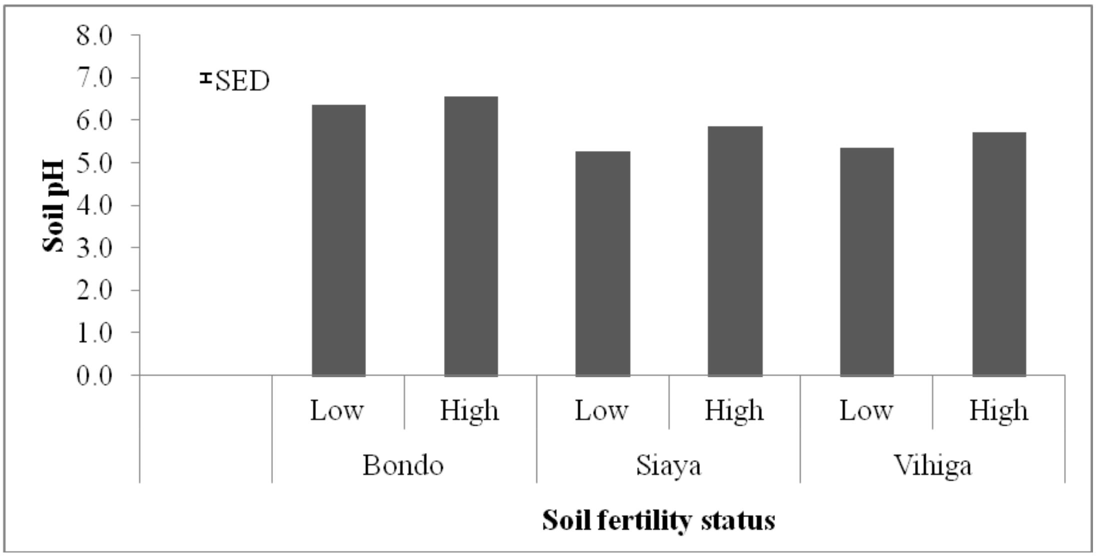


Fig. 2: Effect of soil fertility status on soil pH in Bondo, Siaya and Vihiga at the end of SR2011.

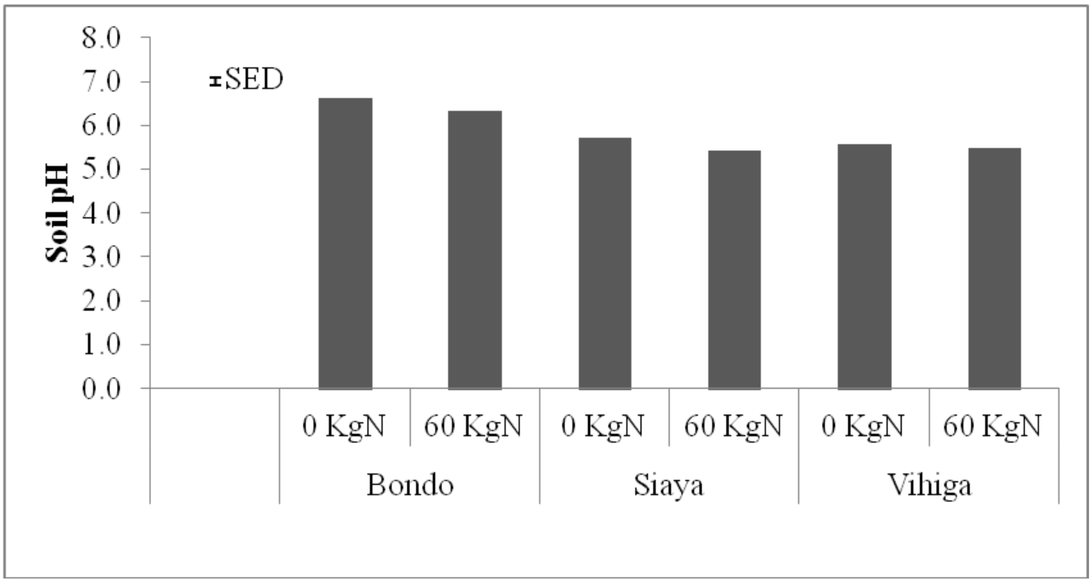


Fig. 3: Effect of nitrogen on soil pH in Bondo,Siaya and Vihiga at the end of SR201

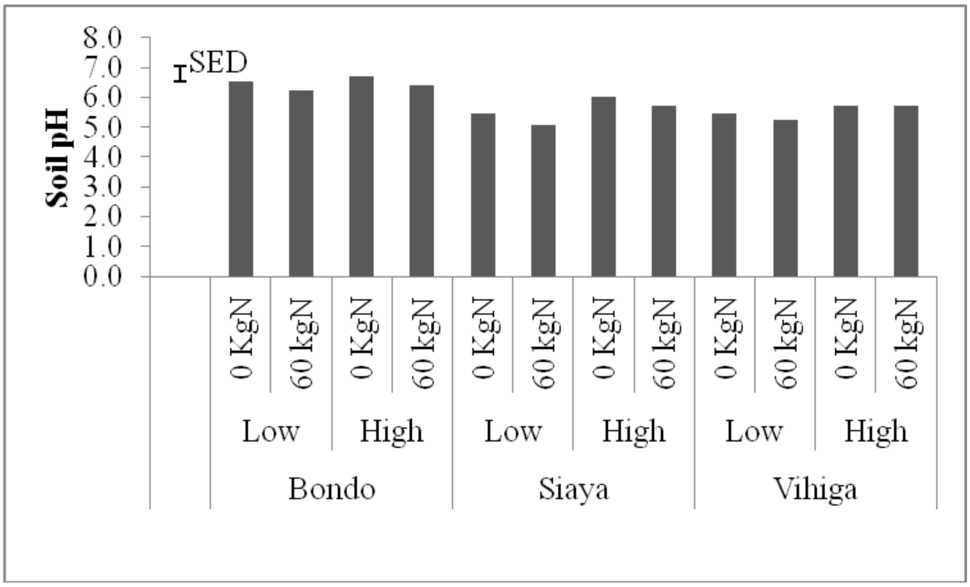


Fig. 4: Effect of nitrogen and soil fertility status interactions on soil pH in Bondo,Siaya and Vihiga at the end of SR2011.

SED: Standard error of the difference, Sites × nitrogen rates x fertility status interaction. Low and high mean fertility low status and fertility high status respectively.

4.1.1. Percentage total nitrogen in soils in the study sites during SR2011 and LR2012.

Fig. 5 shows the results of percentage total nitrogen during the SR2011 and LR2012. The percentage nitrogen differed significantly (P≤0.05) across the sites. In Bondo, Siaya and Vihiga, the percentage nitrogen was 0.22% N, 0.16% N and 0.12% N respectively during SR2011while in the LR2012, the percentage N was 0.14% N, 0.11% N and 0.17% N in Bondo Siaya and Vihiga respectively.

During both SR2011 and LR2012, the fertilized plots had significantly (P≤0.05) higher percentage nitrogen over the unfertilized plots (Fig.6). In Bondo, Siaya and Vihiga, the percentage increase in total N was by 17%, 13% and 21% respectively in SR2011, while in LR2012, the percentage increase was by 18%, 7% and 9% respectively (Fig.6).

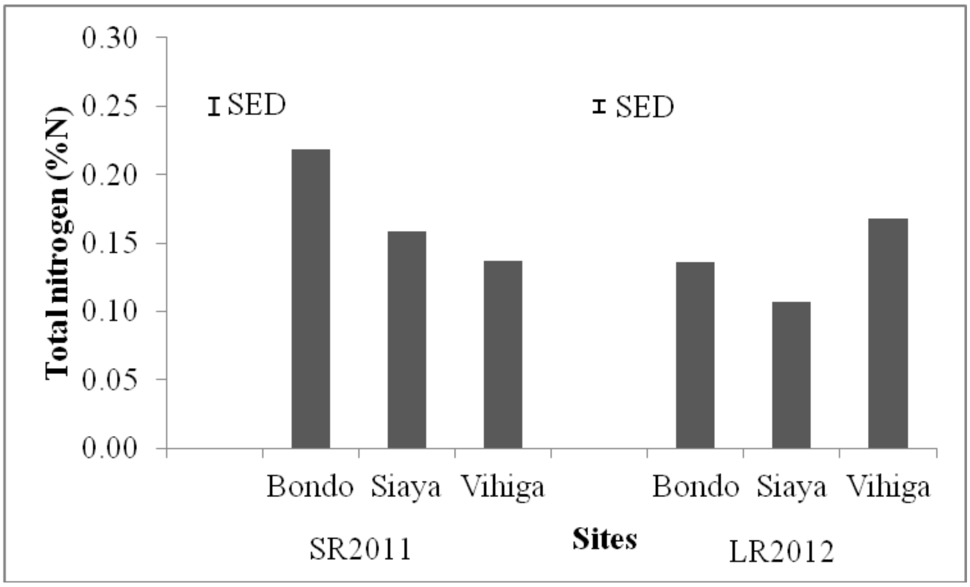


Fig. 5: Percentage total nitrogen in soils in the study sites.

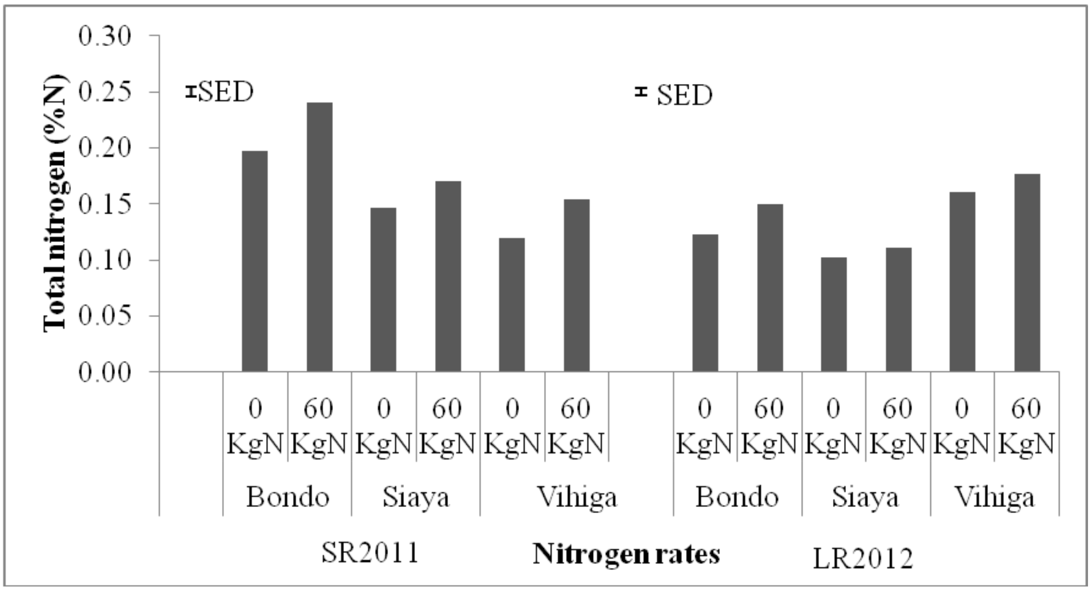


Fig.6: Effect of nitrogen rates on percentage total nitrogen in soils in the study sites.

The results of the effect of soil fertility status on percentage total N during SR2011and LR2012 are presented in Fig. 7. The percentage total N differed significantly (P≤0.05) between the low and high soil fertility status in Bondo and Siaya in SR2011. The high soil fertility status had more nitrogen than the low soil fertility status by 12%, 18% and 4% in Bondo, Siaya and Vihiga respectively. During LR2012, the percentage N did not differ significantly (P≤0.05) in the the low and high soil fertility status across all the sites.

The percentage total N occured due to interaction between sites, nitrogen rates and soil fertility status was significantly (P≤0.05) higher in the fertilized plots in the high than in the low soil fertility status in Bondo during short rainy season (Fig.8).

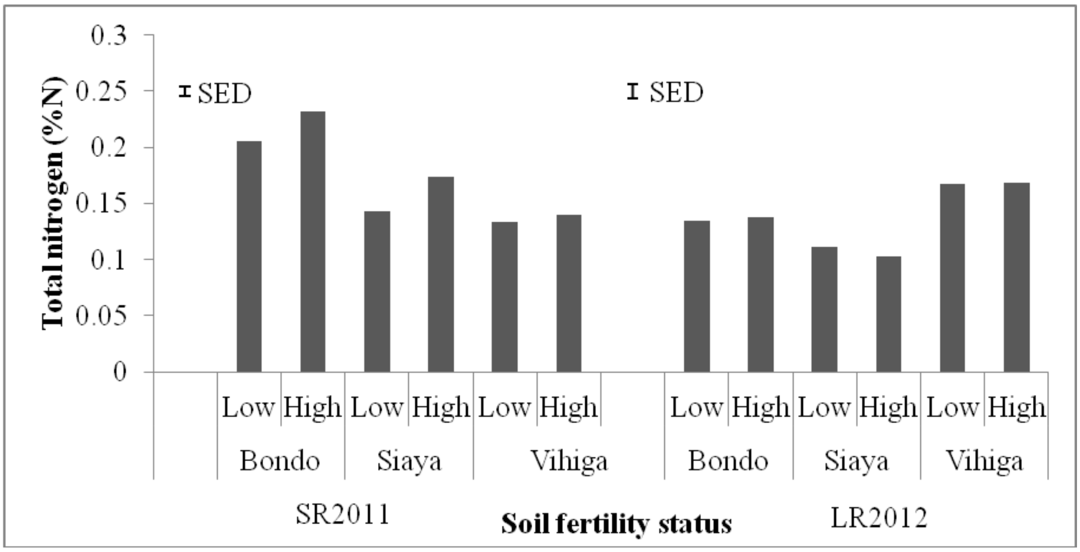


Fig. 7: Effect of soil fertility status on percentage total nitrogen in the study sies.

Low and high means low and high soil fertility status, respectively.

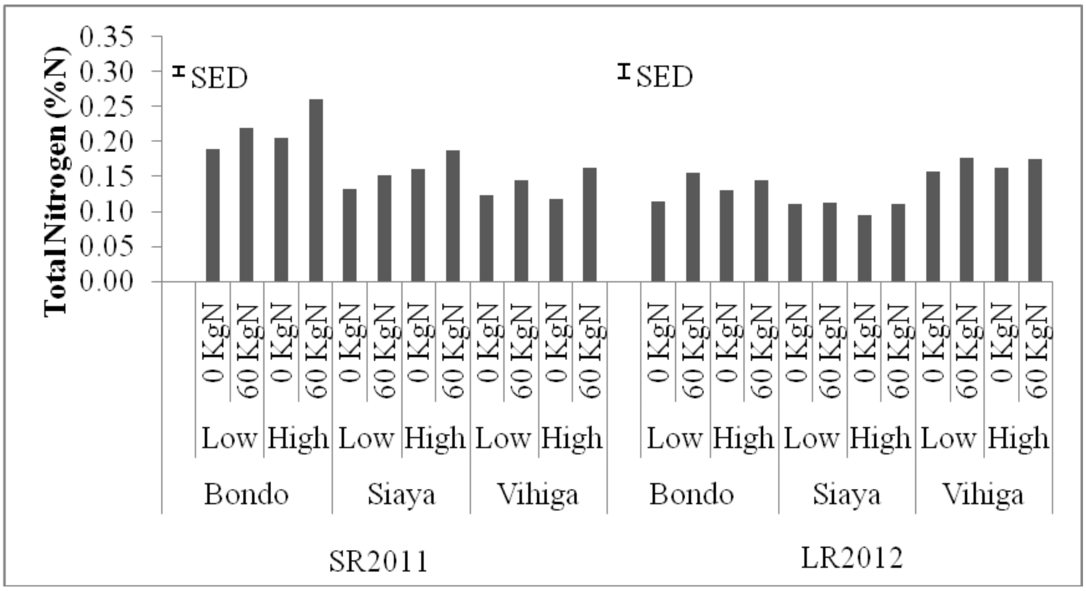


Fig.8: Effect of site, nitrogen rates and soil fertility status interaction on percentage total nitrogen.

SED, standard error of difference for comparison of interaction effect of sites, maize varieties and nitrogen fertilizer respectively; SR2011 and LR2012, short rains of 2011 and long rains of 2012 respectively. Low and high mean fertility low status and fertility high status respectively.

4.2. Effect of maize varieties, nitrogen fertilizer rates and soil fertility status on *Striga* infestation in Bondo, Siaya and Vihiga.

4.2.0. Effect of maize varieties on *Striga* infestation during SR2011 and LR2012.

The herbicide-resistant (IR) maize significantly ($P \leq 0.05$) reduced *Striga* emergence compared to the hybrid variety DH04 during SR2011 and LR2012 in all the three sites. The level of *Striga* infestation was relatively much higher in Bondo than in Siaya and Vihiga. (Fig.9). *Striga* emergence in Bondo, Siaya and Vihiga were 329, 168 and 73

Striga plants per hectare respectively during SR2011. During LR2012, *Striga* plant emerged were 268, 246 and 84 *Striga* plants per hectare respectively.

Hybrid variety (DH04), a commercial hybrid commonly planted by farmers in the region had significantly ($P \leq 0.05$) higher *Striga* emergence (448 *Striga* plants per hectare) than the IR (210 *Striga* plants per hectare) in Bondo. In Siaya and Vihiga, IR maize had significantly ($P \leq 0.05$) lower *Striga* emergence compared to DH04. *Striga* emergence under IR maize was 100 and 28 *Striga* plants per hectare in Siaya and Vihiga respectively. The hybrid maize had 233 and 90 *Striga* plant per hectare in Siaya and Vihiga respectively during SR2011.

During LR2012, *Striga* emergence differed significantly ($P \leq 0.05$) between the two maize varieties in all the three sites. IR maize had significantly ($P \leq 0.05$) lower *Striga* plant emerged than DH04. The *Striga* count values under DH04 were 429, 331 and 121 *Striga* plants per hectare in Bondo, Siaya and Vihiga sites respectively (Fig.10). Generally, IR maize had significantly ($P \leq 0.05$) lower *Striga* emergence than the farmers' practice (hybrid DH04) across the three sites. DH04 was more vigorous and stimulated more *Striga* to emerge than the herbicide-resistant maize. As IR maize emerges and grows, it absorbs some of the herbicide from the seed coat. *Striga* is stimulated to germinate by root exudates (*Striga* lactones) and when the emerging *Striga* attach to the maize roots, it is destroyed before it can cause any harm to the maize plant (Kanampiu *et al.*, 2003). *Striga* counts were relatively higher during SR2011 than during the LR2012 in Bondo (Figs.9 and 10). In Siaya and Vihiga *Striga* emergence were lower in the SR2011 than in the LR2012. Vanlauwe *et al.*, (2008) observed lower *Striga* counts during the short rainy season in Siaya. The low level of *Striga* incidence during short rainy season was thought to be as a result of high soil moisture content that caused *Striga* seeds to undergo dormancy thereby reducing *Striga* emergence. Ransom *et al*., (1996) reported that high soil moisture content reduces soil temperature below the optimum temperature requirement (20-33^{o}C) for *Striga* germination, growth and development.

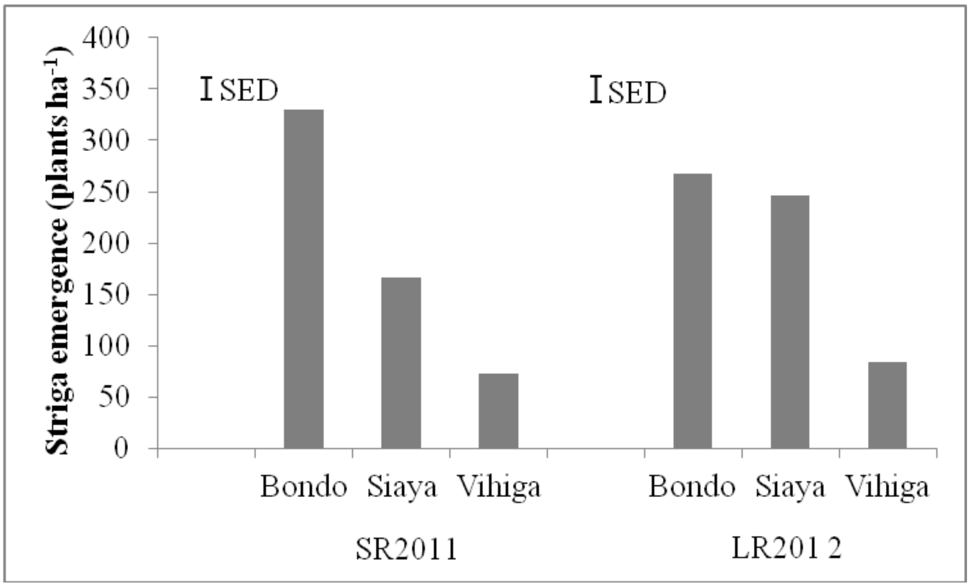


Fig.9: ***Striga*** **emergence in Bondo, Siaya, and Vihiga.**

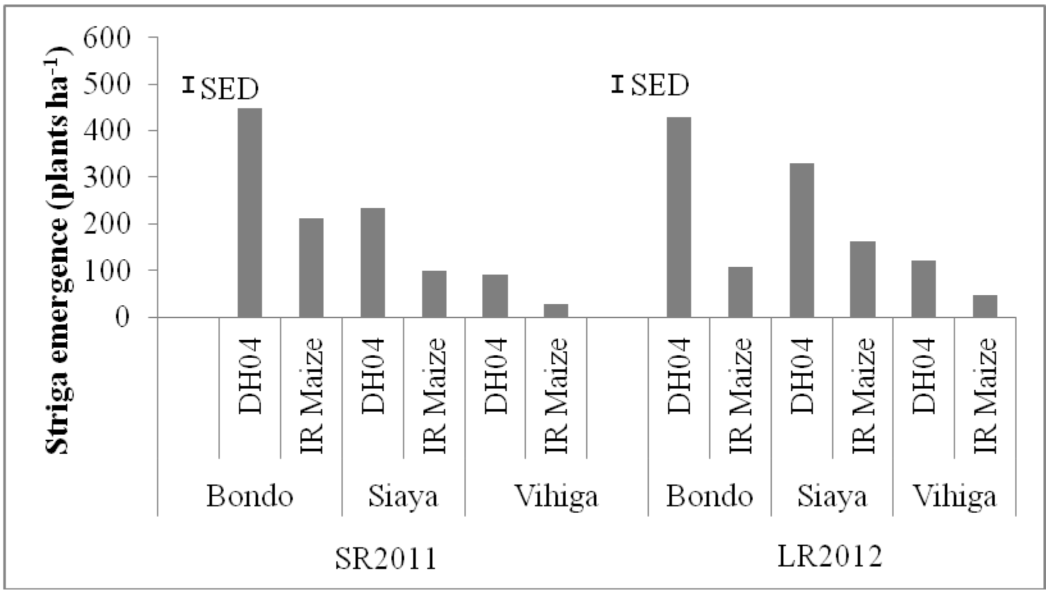


Fig.10: Effect of Maize varieties on Striga emergence in Bondo, Siaya, and Vihiga.

4.2.1. Effect of nitrogen (N) fertilizer rates on *Striga* infestation during SR2011 and LR2012.

Application of N fertilizer was more effective in reducing *Striga* emergence during LR2012 than SR2011in all the sites. N fertilizer significantly ($P \leq 0.05$) reduced *Striga* infestation by 18%, 9% and 22% in Bondo, Siaya and Vihiga respectively during SR2011 (Fig.11). During LR2012 N fertilizer significantly ($P \leq 0.05$) reduced *Striga* emergence by 26%, 18% and 30% in Bondo, Siaya and Vihiga respectively (Fig.11). Vanlauwe *et al*., (2008) observed declining *Striga* infestation with increasing N availability in the soil and reported that the impact depends on the severity of infestation. Nitrogen fertilizer reduces the effectiveness of the maize plant in stimulating *Striga* germination and hence enables the host plant to develop more quickly before *Striga* can act as a parasite (Showemimo *et al*., 2002). It has also been reported that N fertilizer can act as a toxin to *Striga* and cannot be absorbed directly by *Striga*, which prefers to obtain nutrients as amino acids from the host plant (De Groote *et al.*, 2007). Ransom *et al*., (1996) observed reduced *Striga* infestation and increased maize yields while using 60 to 90 kg per hectare of inorganic nitrogen fertilizers.

The results indicate that the benefit of nitrogen was more pronounced in Bondo and Siaya compared to Vihiga. The relatively lower *Striga* emergence in fertilized plots could be attributed to the effectiveness of the system in reducing *Striga* effect.

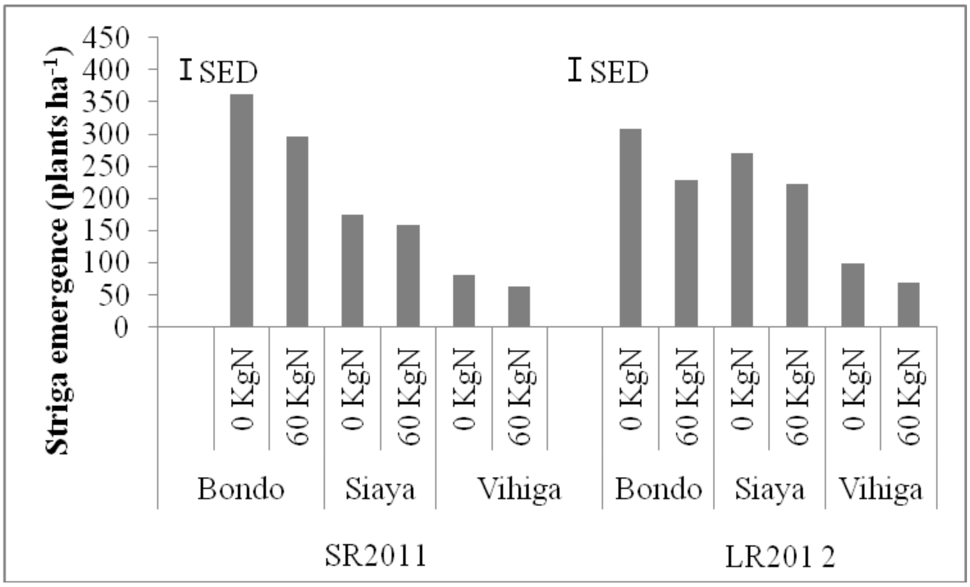


Fig.11: Effect of nitrogen rates on *Striga* emergence in Bondo, Siaya and Vihiga, Western Kenya.

Fig.12 presents the results for the interactions between varieties and N fertilizer rates in the different sites. *Striga* emergence was significantly ($P \leq 0.05$) lower in the fertilized plots with IR maize during SR2011 and LR2012 in Bondo. In Siaya, during LR2012, IR maize with N fertilizer significantly ($P \leq 0.05$) reduced *Striga* emergence. The interaction was not significant in reducing *Striga* effect in Vihiga.

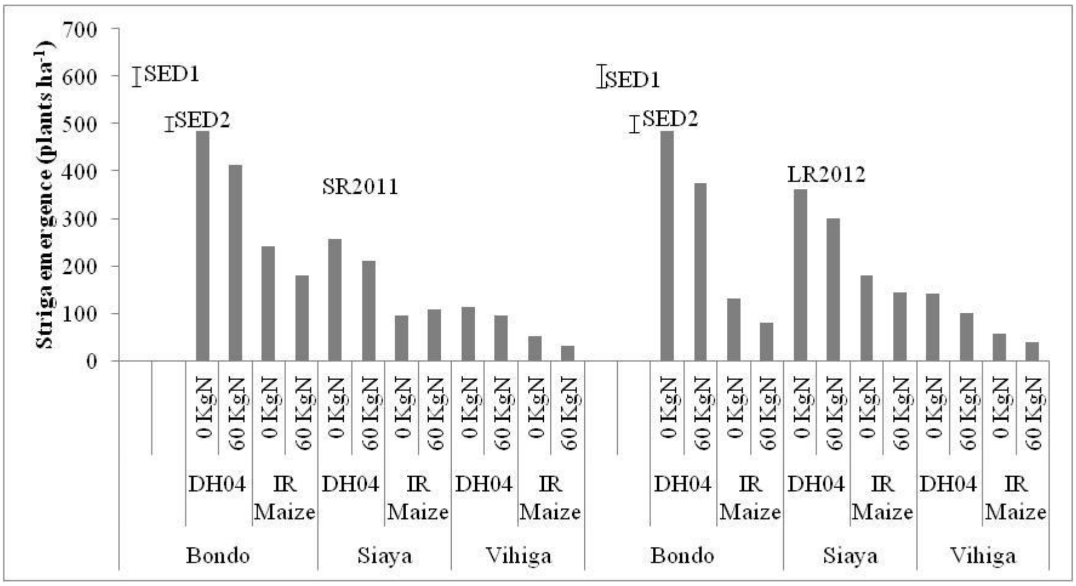


Fig.12: *Striga* emergence in DH04 and IR maize applied with 0 and 60 kg Nha^{-1} of urea nitrogen fertilizer over 2 consecutive seasons.

SED1 and SED2, standard error of difference for comparison of all treatments and for interaction effect of sites, maize varieties and nitrogen fertilizer respectively; SR2011 and LR2012, short rains of 2011 and long rains of 2012 respectively.

4.2.2. Effect of soil fertility status on *Striga* infestation during Sr2011 and LR2012.

In all the three sites, *Striga* emergence was significantly ($P \leq 0.05$) lower in the high soil fertility status compared to low soil fertility status. The *Striga* emergence during SR2011 in the high soil fertility status was 264, 130 and 61 *Striga* plants per hectare in Bondo, Siaya and Vihiga sites respectively while in the low soil fertility status, *Striga* emergence was 394, 204 and 85 plants per hectare in Bondo, Siaya and Vihiga sites respectively (Fig.13). During LR2012, high soil fertility status had significantly lower *Striga* emergence than the low soil fertility status across all the three sites. The high soil fertility status had 210, 148 and 72 *Striga* plants per hectare in Bondo, Siaya and Vihiga respectively while low soil fertility status had 326, 345 and 96 *Striga* plants per hectare in Bondo, Siaya and Vihiga respectively. Poor soil fertility has been reported to be significantly linked to *Striga* infestation (Vanlauwe *et al* 2008). In nutrient poor soils, *Striga* normally flourishes. On the contrary, where soils are managed with adequate quantities of nutrients, *Striga* infestations are minimal or rarely encountered.

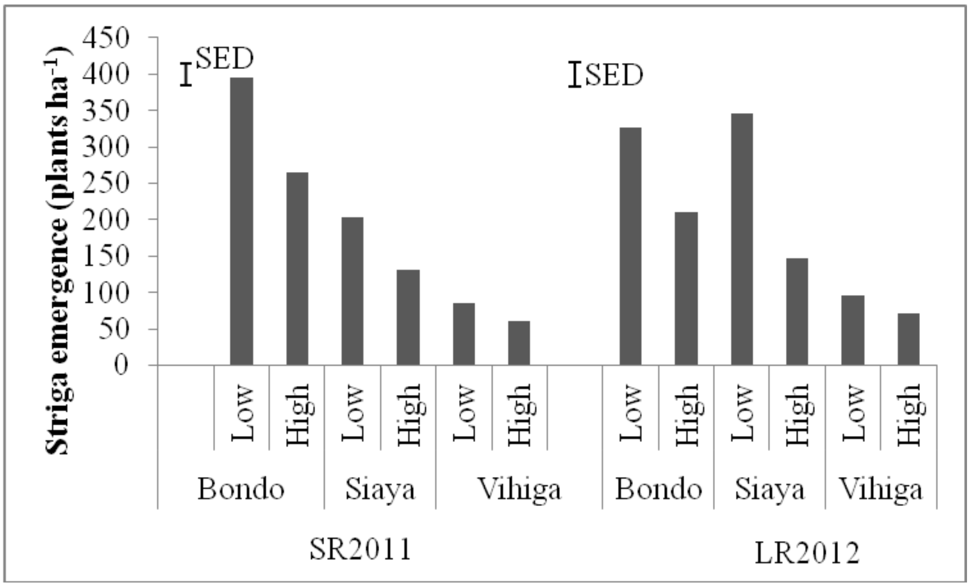


Fig.13: Effect of soil fertility status on *Striga* emergence in Bondo, Siaya and Vihiga, Western Kenya.

During SR2011and LR2012, IR maize in the high soil fertility status had significantly ($P \leq 0.05$) lower *Striga* emergence than IR maize in the low soil fertility status in all the sites (Fig.14). The reduction in *Striga* emergence in plots that had IR maize in the high over low soil fertility status was by 36%, 20% and 39% in Bondo, Siaya and Vihiga respectively during SR2011.

During LR2012, the IR maize reduced *Striga* emergence in the high than in the low soil fertility status by 37%, 62% and 25% in Bondo, Siaya and Vihiga respectively (Fig.14).

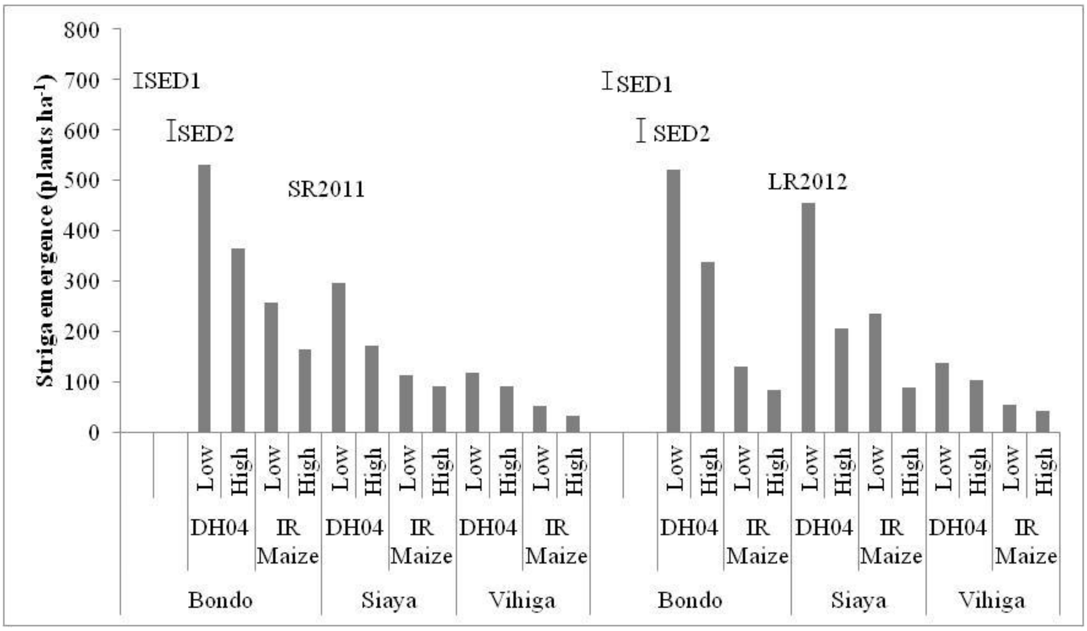


Fig.14: *Striga* emergence in low and high soil fertility status with DH04 and IR maize over 2 consecutive seasons.

SED1 and SED2, standard error of difference for comparison of all treatments and for interaction effect of sites, maize varieties and nitrogen fertilizer respectively; SR2011 and LR2012, short rains of 2011 and long rains of 2012 respectively.

4.3. Maize grain yield (GY) and the effect of nitrogen fertilizer and soil fertility status on maize grain yields under *Striga* infestation.

4.3.0. Maize grain yield (GY) under *Striga* infestation during SR2011 and LR2012.

During SR2011, IR maize grain yield (GY) was significantly ($P \leq 0.05$) higher than the farmers' hybrid DH04. IR maize and DH04 GY were 1.6 and 0.9 tons per hectare (t ha^{-1}) respectively in Bondo. In Siaya IR maize GY significantly ($P \leq 0.05$) out yielded DH04 GY by 0.3 t ha^{-1}, while in Vihiga, IR maize and DH04 GY were 1.5 and 1.3 t ha^{-1} respectively (Fig.15). In the LR2012, IR maize GY differed significantly ($P \leq 0.05$) over DH04. In Bondo, Siaya and Vihiga IR maize GY was significantly ($P \leq 0.05$) higher than

DH04 by 1.1, 1.6 and 0.6 t ha^{-1} respectively (Fig.15). The higher grain yield obtained from IR maize variety was as a result of lower *Striga* emergence observed in this variety. *Striga* parasitism was more prevalent and had significant negative influence in DH04 than IR maize variety. The high *Striga* emergence in the hybrid maize might have been responsible for the low maize yield. *Striga* competes with host plant for nutrients, water and mineral salts and thus reducing host productivity as was in the case of hybrid DH04 grain yield. However IR maize suppressed *Striga* parasitism and produced higher grain yields. Odhiambo and Ariga (2004) found increased maize yield where *Striga* infestation was lower than where it was higher.

Grain yield was higher during LR2012 than during SR2011 (Fig.15). This was perhaps due to influence of *Striga* parasitism which was more prevalent during SR2011than LR2012. This could also have been contributed by the adequate moisture availability during the LR2012.

The results indicate that IR maize variety has a yield advantage over the hybrid variety and yield decline in the latter could have been explained by the higher *Striga* load in the hybrid variety. However, it was observed that decline in *Striga* emergence in hybrid maize occurred with N application. This is an indication that the potential of hybrid variety can be unlocked only with adequate fertilizer to improve soil fertility, timely planting and proper control of S*triga* weed, which may be beyond the economic ability of the majority of farmers. Emphasis on the singular goal of yield maximization may often be in conflict with the farmers' economic viability at the household level where optimization of yield is only one of many factors that inform the farmers' decisions on input use (Mbwaga, 2003).

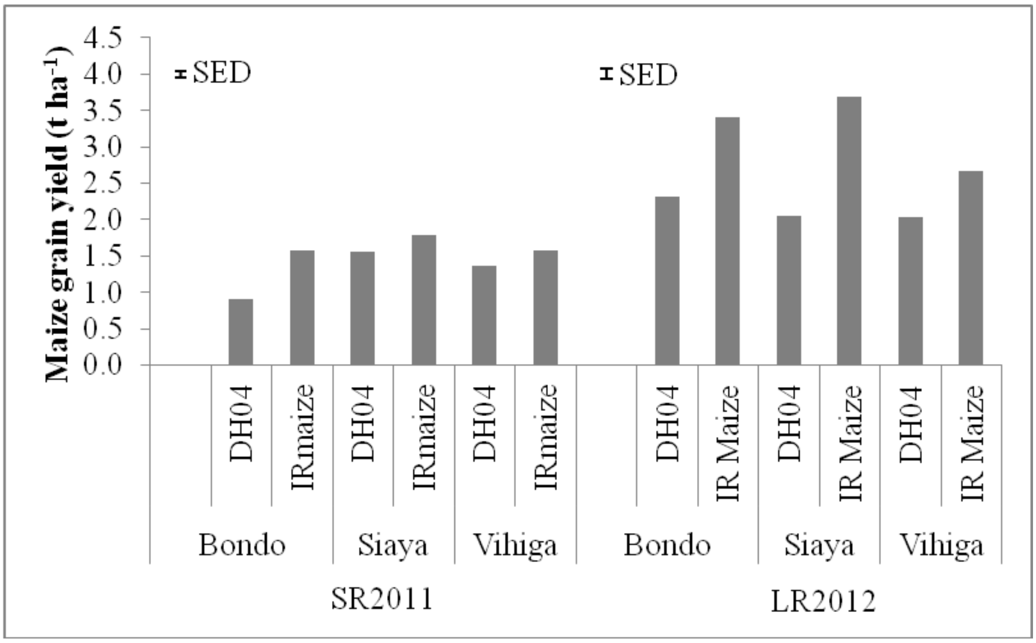


Fig. 15: Maize grain yield in Bondo, Siaya and Vihiga.

4.3.1. Effect of nitrogen rates on maize yield during SR2011 and LR2012.

During SR2011, application of N fertilizer significantly ($P \leq 0.05$) increased maize GY in fertilized over control plots in all the sites. In Bondo, Siaya and Vihiga, N fertilizer increased maize GY by 49%, 38% and 27% respectively (Fig.16). In the LR2012, application of N at the rate of 60 N kg /ha significantly ($P \leq 0.05$) increased maize GY above control in all the sites (Fig.16). The mean GY differed significantly across sites and increased with increasing N rates. The maize GY in the unfertilized control was 2.2, 2.3 and 1.7 hectare ha^{-1}, while in the fertilized plots maize GY was 3.4, 3.5 and 3.0 t ha^{-1} in Bondo, Siaya and Vihiga respectively (Fig.16). Efficient N nutrition in maize is dependent on achieving good synchrony between its availability in soil solution and crop demand (Mwaura, 2003). The common conclusion of many studies on time of N application in maize is that good synchrony occurs with N applied nearest to the time the crop needs it (Gacheru and Rao, 2001). The result of this study suggests that applying N fertilizer may improve crop tolerance to *Striga* and confirms reports by Kifuko-Koech *et al.,* (2012), Mumera and Below (1993), and Ransom *et al*., (1996). Applying starter N at the rate of 25 Kg/ha with a further 35 Kg/ha applied as top dressing can increase grain yield of maize significantly ($P \leq 0.05$) in both *Striga* infested and *Striga* free environments in Western Kenya.

The interactions between IR maize and N fertilizer significantly ($P \leq 0.05$) increased maize GY over the unfertilized treatments during SR2011 and LR2012 in all the sites (Fig.17). In Bondo, Siaya and Vihiga, IR maize GY in the fertilized treatments was higher by 1.1, 1.0 and 0.6 t ha^{-1} respectively during SR2011. The IR maize GY in combination with N fertilizer during LR2012 increased by 1.1, 1.6 and 1.3 t ha^{-1} in Bondo, Siaya and Vihiga respectively (Fig.17).

The positive effect of IR maize and N fertilizer in reducing *Striga* incidence could have contributed to the high maize GY that was obtained with the two combinations. The results clearly indicated that the benefit of nitrogen was more pronounced in Bondo and Siaya than in Vihiga. The relatively high IR maize yield in the fertilized plots could be attributed to the effectiveness of the system in reducing the *Striga* effect.

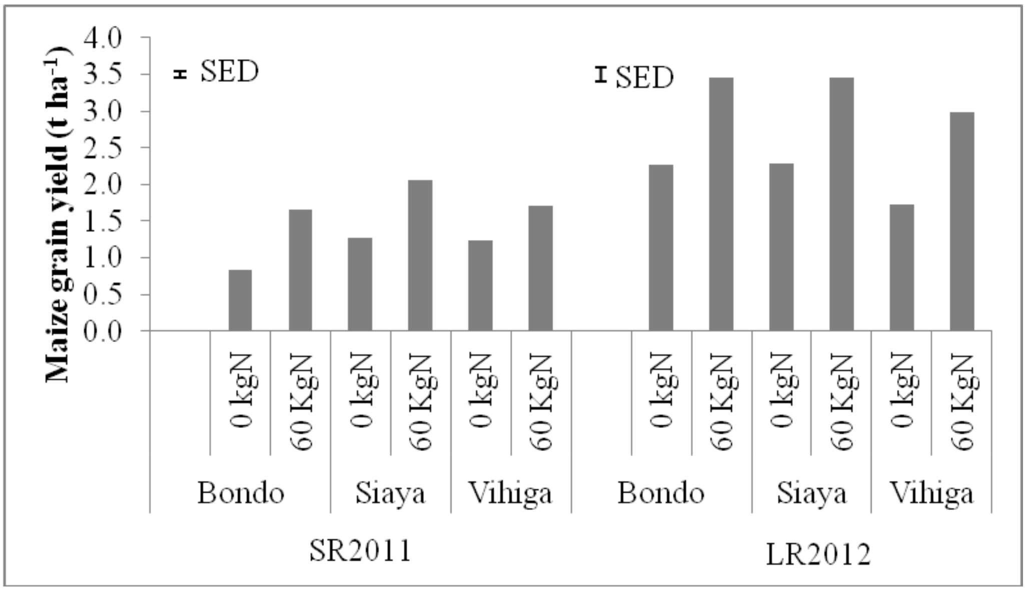


Fig.16: Effect of N application on maize grain yield in Bondo, Siaya and Vihiga, Western Kenya.

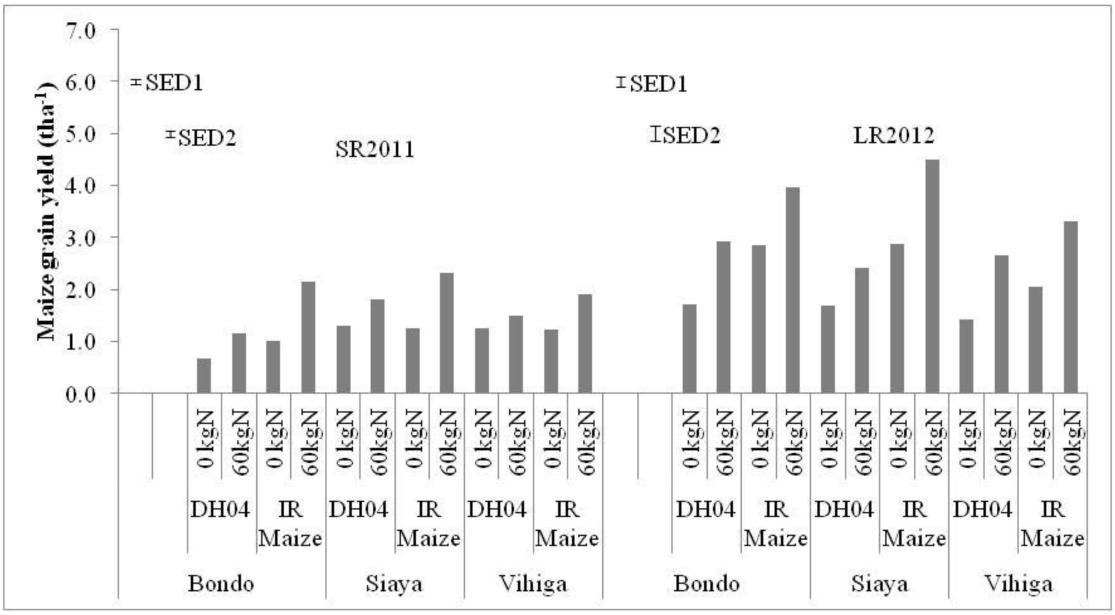


Fig.17: Maize grain yield from DH04 and IR maize applied with 0 and 60 kg Nha^{-1} of urea nitrogen fertilizer over 2 consecutive seasons.

SED1 and SED2, standard error of difference for comparison of all treatments and for interaction effect of sites, maize varieties and nitrogen fertilizer respectively; SR2011 and LR2012, short rains of 2011 and long rains of 2012 respectively.

4.3.2. Effect of soil fertility status on maize yield during SR2011and LR2012.

During the SR2011 and LR2012, maize GY differed significantly ($P \leq 0.05$) in the high than in the low soil fertility status across all the sites. In Bondo, Siaya and Vihiga maize GY in the high soil fertility status out yield GY in the low soil fertility status by 0.6, 0.4 and 0.3 t ha^{-1} respectively while during long rainy season maize GY was higher in the high than in the low soil fertility status by 1.7, 1.4 and 0.7 t ha^{-1} in Bondo, Siaya and Vihiga respectively (Fig.18). The high *Striga* incidence in the low soil fertility status might have been responsible for the low maize yield. Generally, high soil fertility status had higher maize yields than the low soil fertility status.

The mean IR maize GY differed significantly ($P \leq 0.05$) in the high over low soil fertility status across all the sites in both short and long rainy seasons (Fig.19). The IR maize GY was higher in the high than low soil fertility status by 0.5, 0.6 and 0.3 t ha^{-1} in Bondo, Siaya and Vihiga respectively during SR2011 (Fig.19).

During LR2012, the mean IR maize GY increase in the high over the low soil fertility status was by 1.9, 1.7 and 1.0 t ha^{-1} in Bondo, Siaya and Vihiga respectively (Fig.19). The interaction between IR maize and high soil fertility status was useful in increasing maize GY in this variety. There was low *Striga* emergence observed in plots that had IR maize in the high soil fertility status and this might have contributed to the high maize GY (Fig. 19).

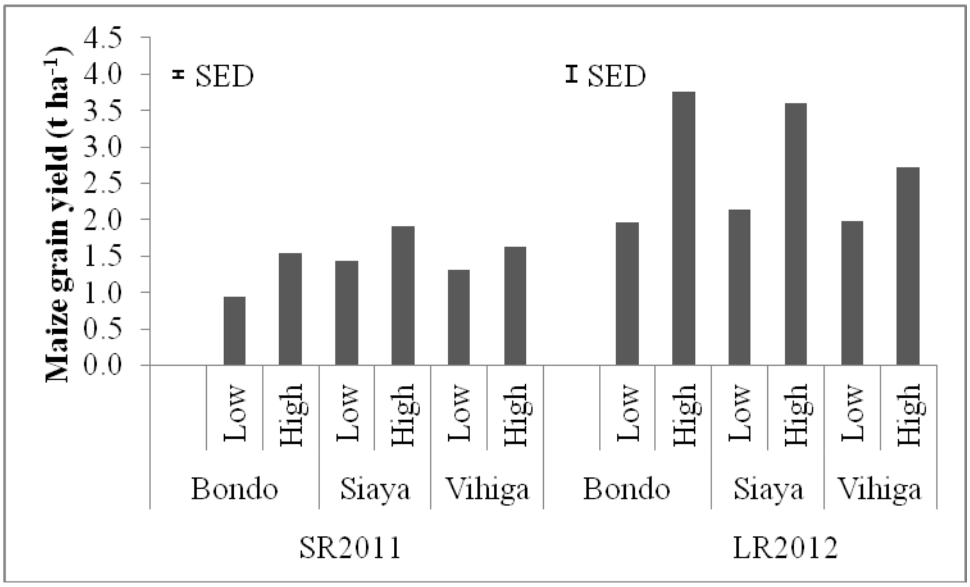


Fig.18: Effect of soil fertility status on maize grain yield in Bondo, Siaya and Vihiga, Western Kenya.

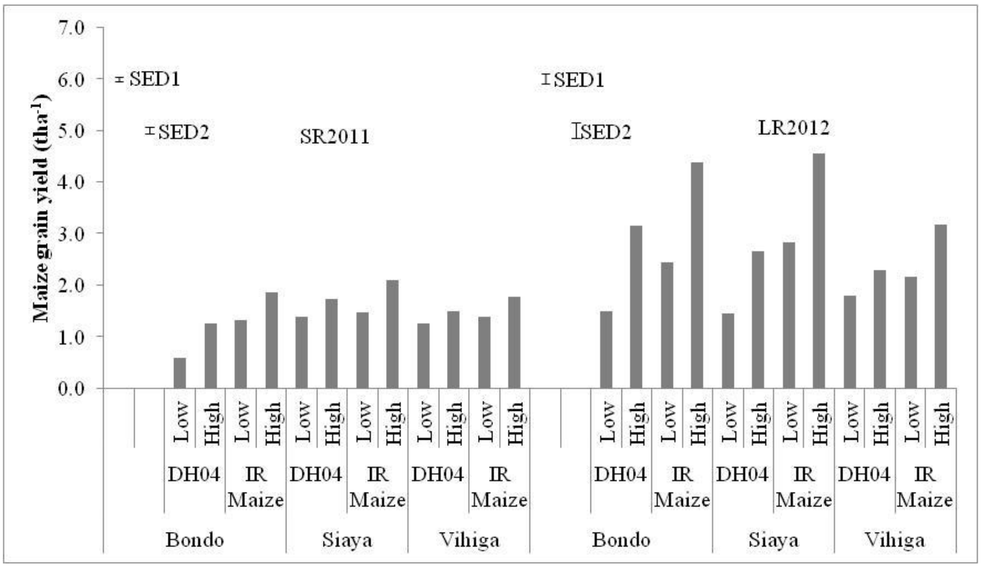


Fig.19: Maize grain yield from DH04 and IR maize applied in the low and high soil fertility status over 2 consecutive seasons.

SED1 and SED2, standard error of difference for comparison of all treatments and for interaction effect of sites, maize varieties and nitrogen fertilizer respectively; SR2011 and LR2012, short rains of 2011 and long rains of 2012 respectively.

4.4. *Striga* seed bank dynamics.

4.4.0. Effect of maize varieties, N fertilizer and soil fertility status on the seasonal changes in the distribution of *Striga* seeds in the soil.

Striga seed bank was significantly (P≤0.05) lower in Vihiga than Siaya and Bondo and reduced across the seasons (Table 9).

The *Striga* seed density significantly (P≤0.05) reduced in plots that had IR maize than DH04 in all the sites across the seasons. DH04 had no significance difference in *Striga* seed bank reduction (Table 10). The *Striga* seed bank reduction in Bondo was by 7% and 57% at the beginning and end of SR2011 respectively and by 23% at the end of LR2012. In Siaya IR maize significantly (P≤0.05) reduced *Striga* seed bank by 32% and 40% at the beginning and end of SR2011 respectively and 34% at the end of LR2012.

Application of N fertilizer had significant effect (P≤0.05) in *Striga* seed bank reduction in Bondo and had no significant effect in Siaya and Vihiga. Significant (P≤0.05) lower numbers of *Striga* seeds were found in the fertilized than in the unfertilized plots (Table 11). The plots that had IR maize and N fertilizer significantly (P≤0.05) reduced *Striga* seed bank by more than 50% in all the sites across the seasons (Table 12). Thus the interaction between IR maize and fertilizer N at the rate of 60 kg N ha^{-1} was significant in reducing *Striga* seeds in the soil. During both SR2011 and LR2012, the high soil fertility status had significantly (P≤0.05) lower *Striga* seed bank density than the low soil fertility status (Table 13). *Striga* Seed bank in the high soil fertility status was lower by 28% at the beginning and at the end of short rainy seaSR2011and by 10% at the end of LR2012 in Bondo (Table 13). In Siaya, *Striga* seeds were significantly (P≤0.05) lower by 37% and 41% under high soil fertility status at the beginning and end of SR2011 and LR2012. In the Vihiga site, *Striga* seed bank was lower under high than low soil fertility status by 36% and 46% at the beginning and end of SR2011 respectively and by 50% at the end of LR2012 (Table 13). The interaction between IR maize and the high soil fertility status significantly had lower *Striga* seed bank densities than the interaction between IR maize and low soil fertility status (Table 14). *Striga* seed densities were unevenly distributed across all the fields at the onset of the crop season, but at the end of the crop season, the seed densities decreased and were generally very low in plots that had IR maize in the high fertility status. This confirms that there was need for an integrated approach.

Maize roots stimulate *Striga* germination, as IR maize germinates and grows it takes up herbicide from the seed coat and soil. When the *Striga* germinating attaches to the maize root, it is destroyed before it can damage the crop. Some *Striga* seedlings are directly killed in the soil. *Striga* seed bank is therefore reduced via suicidal germination and direct action of herbicide on *Striga* seeds. The results of this study agrees with findings of Ransom and Odhiambo (1994) who reported that in treatments without weeding and without fertilizer applications, only a gradual increase of the seed bank occurred over the seasons, but in treatments that were hand weeded the seed bank decreased over the seasons. Between 38 and 55% annual reductions in the *Striga* seed bank took place in weeded treatments (Odhiambo and Ransom, 1994).

Table 9: *Striga* seeds distribution in the soil during SR2011 and LR2012 in Bondo. Siaya and Vihiga.

Striga seed bank density (seeds per hectare)				
Sites	I(S1)	F(S1)	S2	Means
Bondo	10697	9958	8267	9641
Siaya	11130	10567	8969	10222
Vihiga	6398	5614	3437	5150
Means	9408	8713	6,891	
SED(0.05)		823.1		

I (S1) and F (S1) means *Striga* density at the beginning and at the end of SR2011 respectively. S2 means *Striga* density at the end of LR2012. SED$_{(0.05)}$: S- Standard error of difference at 5% significance level for sites.

Table 10: Effect of maize varieties (DH04 and IR maize) on *Striga* seed bank in the soil during SR2011 and LR2012 in Bondo. Siaya and Vihiga.

Season	I(S1)		F(S1)		S2		Means	
Site	DH04	IR maize	DH04	IRmaize	DH04	IRmaize	DH04	IRmaize
Bondo	13763	7632	13890	6025	10959	5575	12871	6411
Siaya	13310	8950	13278	7857	10797	7142	12462	7983
Vihiga	9484	3313	9316	1912	5015	1859	7938	2361
Means	12186	6632	12161	5265	8924	4859	11090	5585
SED$_{(0.05)}$ V*S	813		1164		1071			

I (S1) and F (S1) means *Striga* density at the beginning and at the end of SR2011 respectively. S2 means *Striga* density at the end of LR2012. SED$_{(0.05)}$: V and S*V means standard error of difference at 5% significance level are varieties and the interaction between varieties and N rates respectively.

Table 11: Effect of nitrogen rates on *Striga* seed bank in the soil during SR2011 and LR2012 in Bondo. Siaya and Vihiga.

Seasons	I(S1)		F(S1)		S2		Means	
Sites	0 KgN	60 KgN	0 KgN	60 KgN	0 KgN	60 KgN	0 KgN	60 KgN
Bondo	11005	10389	10124	9792	10914	5620	10681	8600
Siaya	12300	9960	11622	9513	12095	5843	12006	8439
Vihiga	7540	5256	6752	4476	4975	1899	6422	3877
Means	10282	8535	9499	7927	9328	4454	9703	6972
SED (0.05):K	664		672		618			

I (S1) and F (S1) means *Striga* density at the beginning and at the end of SR2011 respectively. S2 means *Striga* density at the end of LR2012. $\text{SED}_{(0.05)}$ K: means standard error of difference for N rates.

Table 12: Effect of nitrogen rates on *Striga* seed bank in the soil during SR2011 and LR2012 in Bondo. Siaya and Vihiga.

Season	I(S1)				F(S1)				S2			
Varieties	DH04		IRmaize		DH04		IRmaize		DH04		IRmaize	
Site	0 KgN	60 KgN	0 KgN	60 KgN	0 KgN	60 KgN	0 KgN	60 KgN	0 KgN	60 KgN	0 KgN	60 KgN
Bondo	14700	12825	7311	7952	14738	13042	5509	6541	13433	8484	8395	2756
Siaya	15271	11349	9329	8571	15201	11356	8043	7670	14904	6690	9287	4997
Vihiga	11742	7225	3339	3287	11562	7070	1942	1881	6567	3464	3383	334
Means	13904	10466	6660	6603	13834	10489	5165	5364	11635	6213	7022	2696
SED: V*K	939				950				874			

I (S1) and F (S1) means *Striga* density at the beginning and at the end of SR2011 respectively. S2 means *Striga* density at the end of LR2012. SED$_{(0.05)}$: V*K means standard error of difference for the interaction between varieties and N rates.

Table 13: Effect of soil fertility status on *Striga* seed bank in the soil during SR2011 and LR2012 in Bondo. Siaya and Vihiga.

Season	I(S1)		F(S1)		S2		Means	
Sites	FLS	FHS	FLS	FHS	FLS	FHS	FLS	FHS
Bondo	12450	8944	11579	8337	8734	7800	10921	6270
Siaya	13675	8584	13311	7823	11072	6867	12686	7758
Vihiga	7834	4963	7333	3894	4592	2282	6586	3713
Means	11320	7497	10741	6685	8133	5650	10064	5914
SED$_{(0.05)}$ F	664		672		618			

I (S1) and F (S1) means *Striga* density at the beginning and at the end of SR2011 respectively. S2 means *Striga* density at the end of LR2012. (FHS) and (FLS) means fertility high status and fertility low status respectively. SED$_{(0.05)}$: F means standard error of difference for soil fertility status.

Table 14: Effect of soil fertility status on *Striga* seed bank in the soil during SR2011 and LR2012 in Bondo. Siaya and Vihiga.

Striga seed bank density (seeds per hectare)												
Season	I(S1)				F(S1)				S2			
Varieties	DH04		IRmaize		DH04		IRmaize		DH04		IRmaize	
Site	FHS	FLS	FHS	FLS	FHS	FLS	FHS	FLS	FHS	FLS	FHS	FLS
Bondo	10233	17292	7655	7608	10488	17292	6186	5865	9948	11969	5652	5498
Siaya	10634	15986	6535	11365	10592	15964	5055	10658	9378	12216	4357	9927
Vihiga	6446	12521	3480	3146	6190	12442	1599	2224	3365	6666	1199	2519
SED$_{(0.05)}$: V*F	939				950				874			

(FHS) and (FLS) means fertility high status and fertility low status respectively. I (S1) and F (S1) means *Striga* density at the beginning and at the end of SR2011 respectively. S2 means *Striga* density at the end of LR2012. SED$_{(0.05)}$: V*F means standard error of difference for the interaction between varieties and soil fertility status.

CHAPTER 5

CONCLUSION

1) The combination of IR maize and N fertilizer significantly increased soil nitrogen, maize yields, reduced *Striga* incidence and *Striga* seed bank.
2) The results showed that *Striga* emergence was higher in the unfertilized than in the fertilized soils. The corresponding maize yields in the unfertilized soils were lower than the yields in the fertilized plots. This was an indication that N fertilizer significantly ($P \leq 0.05$) improved soil fertility status, increased maize grain yields and reduced *Striga* incidence.
3) The high soil fertility status had relatively lower *Striga* incidence, *Striga* seed bank and higher maize grain yield than the low soil fertility status in all sites. Increasing nitrogen rates resulted to an increase in soil nitrogen and maize grain yield.
4) *Striga* emergence was relatively higher during short rainy season than during the long rainy season in Bondo while in Siaya and Vihiga *Striga* emergence was lower in the short than in the long rainy season. The lowest *Striga* densities were observed in plots that had IR maize.

CHAPTER 6

RECOMMENDATIONS

6.0. Recommendation for use.

- Results of this work demonstrated that an integration approach that combine IR maize with inorganic N fertilizer can result in the reduction of *Striga* infestation, seed bank and increase in maize yields in western Kenya. Farmers should therefore use IR maize and N fertilizer to reduce Striga infestation and increase maize yield.

6.1. Recommendation for further research.

- The development of a medium-term program for monitoring *Striga* seed bank in the soil using IR maize and/or other *Striga* control options. This will provide much needed information on the seasonal variations of *Striga* seeds populations and dynamics over a longer period of time. Only then shall we be able to confidently draw conclusions on the effectiveness of IR maize and/or other *Striga* control options for *Striga* management in Western Kenya.
- The elaboration of quantitative tools for the adequate measure of *Striga*-induced yield losses. This is crucial since there are many (biotic and abiotic) factors in the fields that confound the real effects of *Striga* parasitism on maize crops.
- Also, since *Striga* seed bank changes over time and *Striga* infestation increase with declining soil fertility, assessing the contribution of other sources of soil N in the improvement of soil productivity can help decide on which combination to be use to control *Striga* and improve soil fertility.

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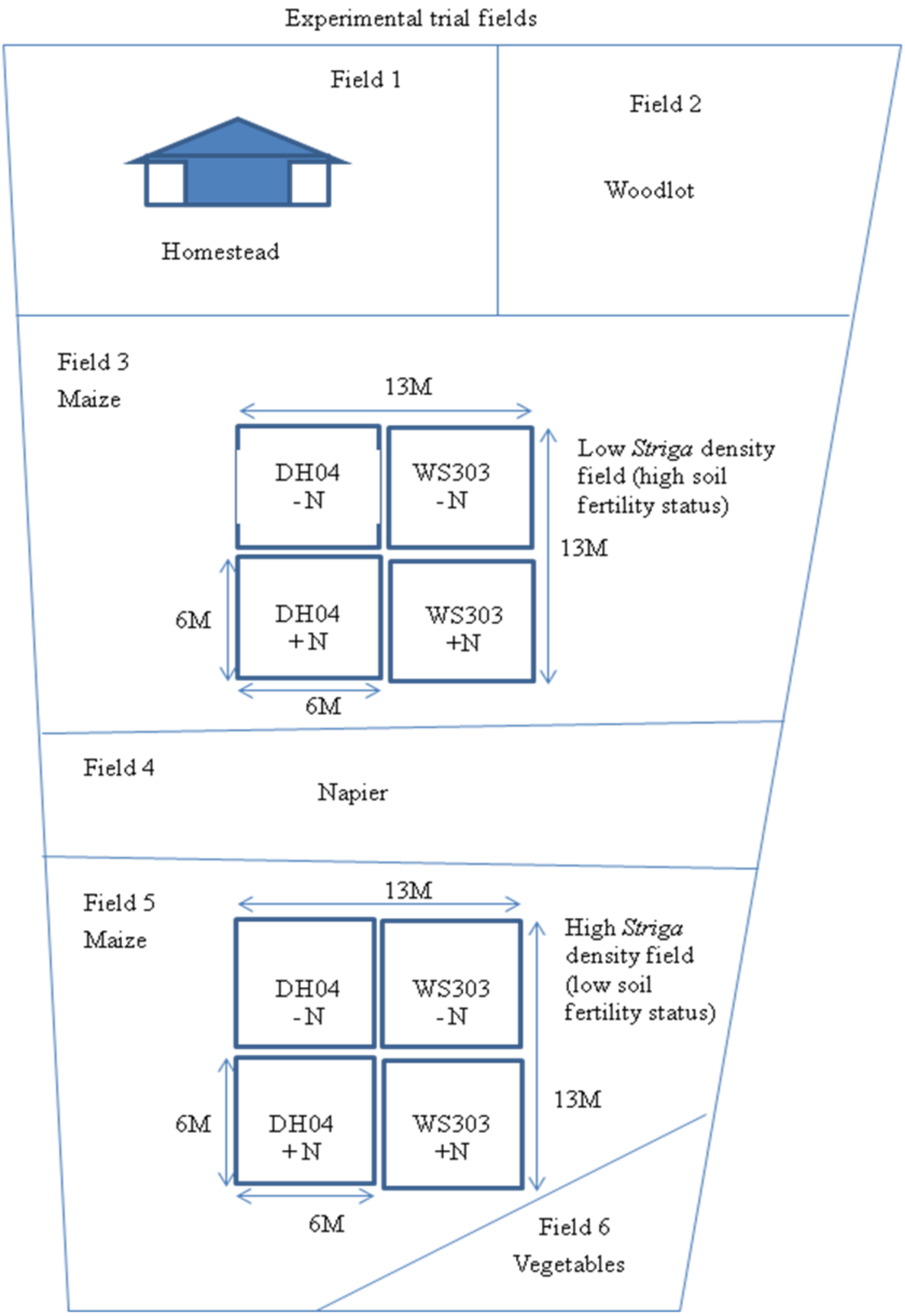
APPEDICES

Appendix I: Experimental layout of the study in Western Kenya.



Appendix II. Summarized analysis of variance of fixed effect of maize grain yield in Bondo, Siaya and Vihiga during short rainy season 2011.

a) Bondo

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
varieties	1	63	58.59	<.0001
Nitrogen level	1	63	86.09	<.0001
varieties×nitrogen level	1	63	13.71	0.0005
Fertility status	1	63	46.2	<.0001
varieties×fertility status	1	63	0.63	0.4313
varieties×nitrogen level×fertility status	1	63	1.65	0.2039

2b) Siaya

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
varieties	1	59	9.32	0.0034
Nitrogen level	1	59	105.35	<.0001
varieties×nitrogen level	1	59	12.13	0.0009
Fertility status	1	59	36.73	<.0001
varieties×fertility status	1	59	3.55	0.0645
varieties×nitrogen level×fertility status	1	59	0.05	0.8203

2c) Vihiga

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
varieties	1	56	8.97	0.0041
Nitrogen level	1	56	49.72	<.0001
varieties×nitrogen level	1	56	11.5	0.0013
Fertility status	1	56	21.92	<.0001
varieties×fertility status	1	56	1.37	0.246
varieties×nitrogen level×fertility status	1	56	0	1

Appendix III: Summarized analysis of variance of fixed effect of maize grain yield in Bondo, Siaya and Vihiga during long rainy season 2012.

3a) Bondo

	Type 3 Tests of Fixed Effects			
	Num	Den		

Source of variation (effect)	DF	DF	F Value	Pr > F
varieties	1	21	28.99	<.0001
Nitrogen level	1	21	33.34	<.0001
varieties*nitrogen level	1	21	0.07	0.8006
Fertility status	1	21	78.13	<.0001
varieties*fertility status	1	21	0.41	0.5269
varieties*nitrogen level*fertility status	1	21	0	0.9815

3b) Siaya.

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
varieties	1	21	34.74	<.0001
Nitrogen level	1	21	17.64	0.0004
varieties×nitrogen level	1	21	2.59	0.1224
Fertility status	1	21	27.53	<.0001
varieties×fertility status	1	21	0.9	0.3545
varieties×nitrogen level*fertility status	1	21	0.93	0.3452

3c) Vihiga.

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
varieties	1	21	15.67	0.0007
Nitrogen level	1	21	60.53	<.0001
varieties×nitrogen level	1	21	0.01	0.9436
Fertility status	1	21	21.55	0.0001
varieties×fertility status	1	21	2.7	0.1151
Nitrogen level×fertility status	1	21	5.79	0.0254
varieties×nitrogen level*fertility	1	21	0.15	0.7052

Appendix IV: Summarized analysis of variance of fixed effect of *Striga* emergence in Bondo, Siaya and Vihiga during short rainy season 2011.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	9	1265694	140633	8	
Sites	2	2697097	1348549	76.7	<.001
Variety	1	1242405	1242405	70.66	<.001

Fertility	1	344620	344620	19.6	<.001
N Level	1	67478	67478	3.84	0.052
Sites×Variety	2	311787	155894	8.87	<.001
Sites×Fertility	2	114697	57349	3.26	0.04
Residual	199	3498897	17582		
Total	231	9670852			

Appendix V: Summarized analysis of variance of fixed effect of *Striga* emergence in Bondo, Siaya and Vihiga during long rainy season 2012.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	9	3321954	369106	15.93	
Sites	2	1614287	807143	34.83	<.001
Variety	1	2124824	2124824	91.7	<.001
Fertility	1	759578	759578	32.78	<.001
N_Level	1	165519	165519	7.14	0.008
Sites×Variety	2	633296	316648	13.67	<.001
Sites×Fertility	2	299676	149838	6.47	0.002
Variety×Fertility	1	114148	114148	4.93	0.028
Residual	199	4611082	23171		
Total	231	13504735			

Appendix VI: Summarized analysis of variance of fixed effect of *Striga* seed bank in Bondo, Siaya and Vihiga during short rainy season 2011.

Bondo

	Type 3 Tests of Fixed Effects			
	Num	Den		
Sources of variation (effect)	DF	DF	F Value	Pr > F

Time	1	140	0.35	0.5556
Varieties×time	1	140	29.28	<.0001
Nitrogen status×time	1	140	0.03	0.862
Varieties×ns×time	1	140	0.01	0.9075
Fertility status×time	1	140	0.29	0.5934
Varieties×fertility status×time	1	140	0.22	0.6393
Nitrogen level×fertility status*time	1	140	0.75	0.3877

Siaya

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
Time	1	60	3.2	0.0789
Varieties×time	1	60	7.1	0.0099
Nitrogen status×time	1	60	0	0.9775
Varieties×ns×time	1	60	0	0.9596
Fertility status×time	1	60	0.07	0.7941
Varieties×fertility status×time	1	60	1.6	0.2109
Nitrogen level×fertility status×time	1	60	0.26	0.6124

Vihiga

	Type 3 Tests of Fixed Effects			
	Num	Den		
Source of variation (effect)	DF	DF	F Value	Pr > F
Time	1	45	4.81	0.0334
Varieties×time	1	45	6.97	0.0113
Nitrogen status×time	1	45	0.11	0.7362
Varieties×ns×time	1	45	0	0.9525
Fertility status×time	1	45	0.19	0.6609
Varieties×fertility status×time	1	45	0.23	0.6354
Nitrogen level×fertility status×time	1	45	0.01	0.9058

Appendix VII: Summarized analysis of variance of fixed effect of nitrogen status during SR2011.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.0000333	0.0000333	0.11	
Sites	2	0.0577625	0.0288813	98.94	<.001
F_status	1	0.0056333	0.0056333	19.3	<.001
N_level	1	0.0133333	0.0133333	45.68	<.001

Sites×F_status	2	0.0014542	0.0007271	2.49	0.097
Sites×N_level	2	0.0007042	0.0003521	1.21	0.311
F_status.N_level	1	0.0010083	0.0010083	3.45	0.072
Residual	35	0.0102167	0.0002919		
Total	47	0.090325			

Appendix VIII: Summarized analysis of variance of fixed effect of nitrogen status during LR2012.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.000675	0.000675	1.22	
Sites	2	0.0300292	0.0150146	27.19	<.001
F_status	1	0.0000333	0.0000333	0.06	0.807
N_level	1	0.003675	0.003675	6.66	0.014
Sites×F_status	2	0.0003042	0.0001521	0.28	0.761
Sites×N_level	2	0.0007125	0.0003562	0.65	0.531
F_status×N_level	1	0.0001333	0.0001333	0.24	0.626
Residual	35	0.019325	0.0005521		
Total	47	0.0555917			

Appendix VIX: Rainfall data during SR2011 and LR2012 in the study sites.

Site	Bondo		Siaya		Vihiga	
Year	2011	2012	2011	2012	2011	2012
Month	Rainfall (mm)		Rainfall (mm)		Rainfall (mm)	

January	64.8	47	86	134.3	195.4	131.4
February	35.8	161.8	54.7	45.1	82.3	156.3
March	123.6	59.9	156.3	183.8	56.6	157.4
April	149.7	213.7	311.9	201	274.4	240.3
May	149.9	294.3	86.1	229.4	121.2	164
June	36	109.7	76.3	160.5	67.2	93
July	89	26.2	92.5	67.5	39.2	183.1
August	77.3	76.7	119.2	172.2	35.7	301.8
September	152.5	67.7	95.1	267.1	39.3	273.7
October	146.9	242.5	66.1	175.4	328.7	182.7
November	42	32	250.3	143.7	325.9	68
December	4	89.7	228.2	137.5	119.8	12
Total	1071.5	1421.2	1622.7	1917.5	1685.7	1963.7