Swedish University of Agricultural Sciences
Department of Soil and Environment

Soil fertility status and *Striga hermonthica* infestation relationship due to management practices in Western Kenya

Miriam Larsson

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Supervisors: Kristina Röing de Nowina, Department of Soil and Environment, SLU & Håkan Marstorp, Department of Soil and Environment, SLU
Assistant supervisors: Anneli Lundkvist, Department of Crop Production Ecology, SLU & Bernard Vanlauwe, Department of Soil and Environment, SLU and TSBF-CIAT, Nairobi, Kenya
Examiner: Erik Karltun, Department of Soil and Environment, SLU
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Cover: Striga hermonthica in a maize stand in Vihiga, Western Kenya. Photo by author.

The thesis is a part of an on-going research project, funded by Sida/FORMAS, at the Department of Soil and Environment, SLU, Sweden in collaboration with TSBF-CIAT (Tropical Soil Biology and Fertility Institute of CIAT). The project activities are located in Western Kenya, sub-Saharan Africa where the occurrence of the parasitic weed *Striga hermonthica* is a major threat to crop production; the project aims to evaluate the relationship between soil properties and *Striga hermonthica*.

ABSTRACT

Striga hermonthica, a parasitic weed, has long been believed to be correlated with the declining soil fertility status. However scientists have recently come to question this statement since some recent studies have shown contradictive results. To investigate whether soil fertility status and infestation of *Striga hermonthica* were correlated and the impact of it were caused by farmer management, 120 farmers in Western Kenya, where *Striga hermonthica* infestation is prone, participated in this study. In three districts with two sub-locations each, farmers answered a structural questionnaire and identified two fields, one with high and one with low soil fertility. These fields later came to be the basis for this study and soil were therefore also sampled from them. Different soil variables such as: pH, ohlsen-P, texture, C, N, and seed bank of *Striga hermonthica*, were then analyzed. The *Striga* seed bank differed significantly between the districts, but there were no differences between the farms or the two fields (high and low soil fertility) on each farm. pH, C and N gave significant results for the amount of *Striga* seeds found in the soil. Soils with lower C:N ratio also contained fewer *Striga* seeds, while fields with high pH had more *Striga* seeds present. In Nyabeda, one of the sub-locations, trials were installed on the identified fields at 11 farms to measure actual *Striga* emergence in the field. Local and IR-maize were planted, both with and without fertilization. Variety was significant for both *Striga* emergence count and maize yield. Field status was also significant for *Striga* emergence. Fertilisation played no significant role in *Striga* emergence nor did it increase the yield. The local maize variety gave significantly higher yields than the IR-maize did. Furthermore IR-maize resulted in significantly higher emergence of *Striga*. *Striga* infestation seems to be correlated with soil fertility status, though the impact of farmer management has not been fully investigated due to the limited amount of time and data available. Further studies are needed to understand the impact of farmer management practices on *Striga* infestation and soil fertility.

SAMMANFATTNING

Man har länge ansett att det parasitiska ogräset *Striga hermonthica* gynnas av minskad markbördighet. Nyare studier har ifrågasatt detta samband. I denna studie, som gjorts i västra Kenya, ett område med stora angrepp av *Striga hermonthica,* deltog 120 bönder. Studiens syfte var att undersöka om det finns ett samband mellan markbördighet och skördeminskningar orsakade av *Striga hermonthica* och hur detta samband har påverkats av gårdarnas brukningshistoria. I tre distrikt med två underdistrikt vardera fick bönderna i intervjuer svara på frågor från strukturerade frågeformulär samt identifiera två fält på sina gårdar, ett med hög och ett med låg markbördighet. Provtagningar från dessa fält ligger till grund för denna studie. Markvariabler såsom pH, Ohlsen-P, textur, C, N och *Striga hermonthica*s fröbank analyserades på jordprover insamlade från dessa fält. Mängden *Striga* frön skiljde sig åt mellan de olika distrikten. Däremot kunde ingen skillnad mellan gårdarna eller mellan de båda typerna av de identifierade fälten påvisas. *Striga*s fröbank visade på samband med markens pH och innehåll av C och N. Jordar med lägre C:N kvot hade också lägre antal frön i jordproverna, medan fält med högt pH innehöll mera frön. I Nyabeda, ett av underdistrikten, lades fältförsök ut på 11 gårdar för att skatta uppkomsten av *Striga* i fält. Där planterades både en lokal majssort och s.k. IR-majs som på *Striga*-infetkterade fält ger högre avkastning på grund av bättre resistens mot *Striga*. Båda majssorterna fick sedan behandlingarna gödslat och ogödslat. Försökens resultat visade att planträkningen för uppkomna *Striga*-plantor berodde på vilken majssort som odlades. Uppkomst av *Striga* berodde även på om fälten hade identifierats ha hög eller låg markbördighet. Huruvida fälten var gödslade eller inte tycktes inte påverka antalet uppkomna *Striga*-plantor. De gödslade rutorna visade heller ingen skördeökning. Lokal majs gav högre skördar än vad IR-majsen gjorde. I de rutor där IR-majs hade planterats var antalet uppkomna *Striga*-plantor högre. *Striga*-angrepp verkar bero på markbördighet. Däremot har inte påverkan av böndernas brukningsätt kunnat studeras fullt ut. Detta på grund av begränsningar i tid, modell och data. Fler studier behöver göras för att bättre förstå hur böndernas brukningssätt påverkar förekomsten av *Striga*-angrepp och markbördighetens utveckling.

GLOSSARY

ABA-level	abscisic acid (ABA) a hormone which regulates seed maturation and dormancy. It is also an anti-stress signal in the plant.
Acre	= 0.404685642 hectares
Asynchronous intervals.	not synchronized. The seed do not germinate at predetermined or regular
Exogenous	something that comes from outside the system
Haustorium	a specialized hyphae that can penetrate a plants cell wall.
Half-moons	bunds shaped like half-moon, 2 to 6 meters in diameter, which can harvest runoff water from 10 to 20 m^2 and on cereals or tree can grow on. A quick and easy method for harvesting water in semi-arid areas.
Soil Auger	a device used to manually drill in the soil and thereby collect a one piece soil sample
Tied Ridges	ridges with 1 to 2 meters space in between (uncultivated strip). From this strip runoff is collected and stored in a furrow located above the ridges. On both sides of the furrow crops are planted (mainly cereals).
TLU	(Tropical Livestock Unit) is a standardized method of quantifying different livestock types and is a measurement for total owned livestock at household level. Cattle = 0.70, sheep and goats = 0.10, pigs = 0.20 and chicken = 0.01.
TSBF	TSBF-CIAT (Tropical Soil Biology and Fertility Institute of CIAT)

CONTENTS

1. INTRODUCTION

Several million hectares of arable land in the world are infected by the parasitic weed species Purple witchweed (*Striga hermonthica* (Del.) Benth.), henceforward only referred to as *Striga*, (Albert and Runge-Metzger, 1995), which causes crop losses of billions of $US annually. It is estimated that 50 million ha and 300 million farmers in sub-Saharan Africa (SSA) are affected. That equals to an infestation corresponding to 40% of the arable land and to crop losses of about 7 billion $US yearly (Parker, 2008 Lagoke et al. 1991). This is especially serious in an inhabited area where 33% of the population is estimated to be undernourished (Lagoke et al. 1991). Cereals are considered to be the most sensitive crops for infection by this weed (Abunyewa and Padi, 2003) and in East and South Africa mixed cropping systems with maize (*Zea mays* L.) are the most important food production system (Waddington et al. 2009). As much as 21% of the total maize area in East Africa is infested by *Striga* and it is considered to be extra severe there as well (Parker, 2008). Studies have shown that *Striga* can reduce the yield to almost zero (Hassan et al., 1995), which may lead to the farmer abandoning the fields when they are no longer productive (Review by Berner et al. 1995). In that way *Striga* infestation leads to degradation of agricultural land when the farmer no longer care for those fields (Abunyewa and Padi, 2003) and some studies claim that problems caused by *Striga* continue due to loss of soil fertility since low soil fertility would benefit *Striga* (Parker, 2008). According to Parker (2008) problems with *Striga* are generally caused by low economic resources, poor soil fertility, newly infested areas due to unclean sowing material and cropping of host crops. "Soil fertility is increasingly being recognized as a fundamental biophysical root cause for declining food security in the smallholder farmers of SSA" (Sanchez and Jama, 2002; Vanlauwe et al., 2002). In the SSA region crop residues are commonly removed from the fields. Here decomposition and mineralization of soil organic matter occur at a high rate since the soil temperature is much higher compared to e.g. Europe. These factors plus the non-use of fertilizers lead to soil degradation. (Abunewa and Padi, 2003) The increase of *Striga* infestation and linked problems with *Striga* are mainly due to an increased food production because of the rapid population growth in Africa. Traditionally, intercropping, crop rotations and fallow were commonly used to control weeds such as *Striga*. With an increased food demand, these old practices were abandoned and nowadays mono-cropping without use of fallow is the common way of cropping. This has benefited *Striga* and the infestation has increased. Also the abandonment of old native cereal varieties to new high-productive cereals, such as maize, benefits *Striga*. Since maize is not a native crop to Africa it has a low tolerance towards the weed (Review by Berner et al. 1995).

Striga has been thought to be extra troublesome in areas which already suffer from low soil fertility, low rainfall and where no or little fertilizer is used (Sauerborn et al., 2003; Gurney et al., 2006), which is a typical scenario for Western Kenya (Vanlauwe, 2011 pers.). 76% of cereal cropping areas in Kenya, maize and sorghum, is infested by *Striga* (Kanampiu et al., 2002). This gives an annual loss of about 41 US$. (Hassan el al, 1995) Recommendations on how to control *Striga* have been to increase the soil fertility, e.g. have higher contents of soil organic matter and nitrogen. High soil fertility is thought to improve cereals in its competition against *Striga* and also reduce the germination stimulant produced by it (Abunewa and Padi, 2003). Later however scientists have come to question the statement that the soil fertility grade and the rate of *Striga* should be correlated (Vanlauwe, 2008), therefore the need for further studies on this matter.

The overall aim of this study was to examine the relationships between soil fertility status and *Striga* pressure affected by soil management practices in Western Kenya. This was done by: 1) measuring *Striga* germination through trials and *Striga* seed bank in fields of different

fertility status and 2) investigate the impact of farm management on soil fertility status and *Striga* pressure. The expected results were that fields with low soil fertility would have higher *Striga* density and a higher content of seeds in the soil than fields with higher soil fertility. Farmers were also presumed to know which fields have high respective low soil fertility and high and low *Striga* infestation. The main hypotheses were: 1) correlation between *Striga* and soil fertility status: fertile soils have a lower *Striga* seed bank and germination values compared to unfertile soils 2) farmers know which of their fields have high or low soil fertility status, respectively.

2. BACKGROUND

2.1 Striga hermonthica (Del.) Benth.

There are 30 to 35 different species of the genus *Striga* found in the world, and about 23 of these species can be found in SSA (Gethi et al. 2005, review by Berner et al. 1995). *Striga* species are one of the most troublesome and damaging weed species in the world (Parker, 2008). Especially those who infest agricultural crops are of great economic importance and the most important *Striga* species are Purple witchweed (*Striga hermonthica* (Del.) Benth.) and Asiatic witchweed (*Striga asiatica* (L) Kuntze). *Striga hermonthica* has been studied here and will henceforth be referred to as *Striga*. *Striga* is an obligate (review by Berner et al. 1995) chlorophyll-bearing (Cook et al. 1972) root parasite, which means that the weed is dependent on its plant host during its entire life cycle, germination – flowering – reproduction, see fig 1.

The seeds of *Striga* are very small, with an average weight of 7 µg/seed (review by Berner et al. 1995). Before the seeds are able to germinate, they need to have undergone warm conditions, 25-40 degrees Celsius (30°C is the optimal) under at least a period of four days and (Cardoso et al. 2010, Muller et al. 1992), exposed to the right pH and light conditions (Magnus and Zwaneburg, 1992). Germination without any stimulants rarely occurs. If the seeds are not exposed to the stimulant the germination ability decreases and they enters into secondary dormancy. When the seed has started to germinate, the haustorium develops which attaches to the host plant. A xylem-xylem connection is created between the haustorium and the host plant, in that way the seed can withdraw water and nutrients from the host plant. (Cardoso et al. 2010).

Since *Striga* is a parasitic weed the seedlings cannot sustain themselves on their own resources for particular long after germination. Therefore they need to find a host root shortly after germination and the germination needs to be perfectly timed with the presence of a host root. Exogenous germination stimulants called strigolactones are produced by the host's root and also by some non-host (usually referred to as trap crops) roots (*Gossypium* sp.). They are plant hormones which inhibit shoot branching (Gomez-Roldan et al. 2008) but also signals to seeds of parasitic weeds such as *Striga* to start germinate. Strigolactones are also involved in other physiological processes such as abiotic response and the regulation of the plants structure is also regulated by strigolactones. Strigol, a synthetic compound belonging to the strigolactones, was first isolated from cotton (*Gossypium* sp.) and is used as a germination trigger for *Striga* (Cardoso et al. 2010).

When the seed have been germinated the seedling can live for 3 to 7 days without a host. After that it will die if it is not attached to a root and there has been able to create a parasitic link to that particular root. The seedling finds its way to the host root by chemical signals and then creates a xylem-to-xylem connection between the seedling and the root, see fig 1. However the seedling cannot be at a greater distance from the root than 2 to 3 mm to find its way there. When the seedlings have attached to the root it grows underground for 4-7 weeks before they emerge and are actually seen in the field, see fig 2. One plant can host many *Striga* plants and *Striga* affects the plant mostly before its emergence. The symptoms are however hard to distinguish from symptoms caused by drought, lack of nutrients and other diseases. The *Striga* plant flowers 4 week after emergence, after 4 more weeks the seeds are mature. Every plant produces as much as 50,000 to 500,000 seeds and they are viable up to 14 years in the soil (review by Berner et al. 1995).

It is not fully understood in all ways *Striga* infestation affects the host plant, but some studies indicate that transpiration and photosynthesis are reduced and ABA-level is increased

(Cardoso et al. 2010). Crop species and genotypes within the same species have different abilities to induce germination of *Striga* due to the content of their root exudates (Traore et al. 2011).

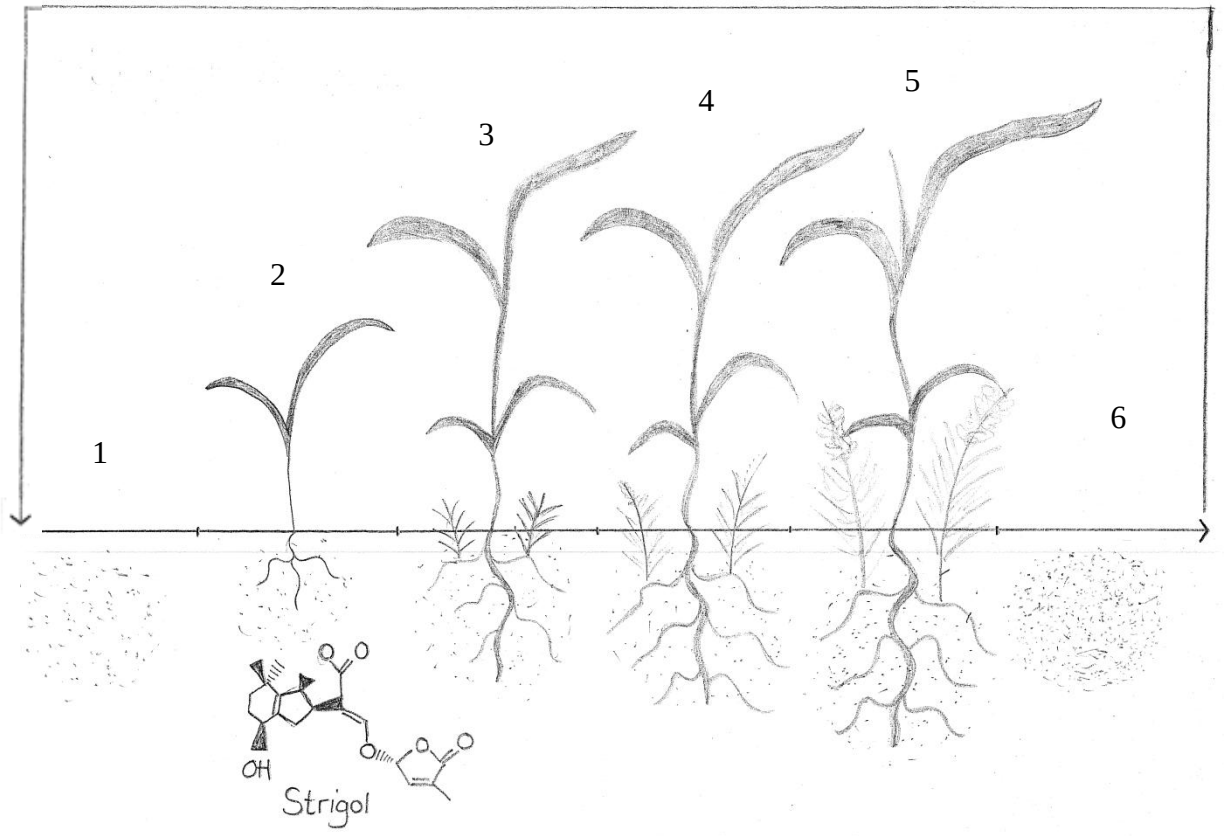


Figure 1. *Striga* lifecycle on maize. 1. Seeds present in the soil. 2. The root of maize produces strigol which stimulate *Striga* to germinate. 3. The seedlings attach to the maize root and start its parasitic life. *Striga* grow 4-7 weeks underground before it emerges. 4 & 5. 4 weeks after emergence *Striga* flowers. After 4 more weeks the seeds are mature. 6. A *Striga* plant produces as much as 50 000 to 500 000 seeds. The seeds add up to the seed bank in the soil where they can stay viable for up to 14 years. Drawing after figure in a Review by Cardoso C et al.: Miriam Larsson.

Figure 2. *Striga hermonthica* in infested field in Nyabeda, Siaya district, Western Kenya. Photo: Miriam Larsson.

Striga seeds can be spread by livestock grazing on the fields. About 8 per cent of seeds digested by cattle remain viable after the passage through the animals. Long distance spreading of *Striga* is mainly caused by contaminated seeds used for sowing. By using seeds from reliable seed companies, the spreading of *Striga* may be reduced. If the infection of *Striga* can be delayed for 4 to 6 weeks, the crop yield will increase and *Striga* emergence and reproduction decreases. When the host root is older than 4 weeks the germination effect on *Striga* declines. Also the physical barrier due to thicker root prevents the seedling to attach to it. Parasitic weeds have a direct negative affect on the crop in contrast to non-parasitic weeds which have an indirect negative affect on ditto. Non-parasitic weeds compete with the crop for water, nutrients, space etc. Parasitic weeds such as *Striga* rather steal nutrients and water from its host – the crop. For all kind of weed control preventive methods are important, but for parasitic weeds is it even more crucial since the weed harms the crop directly after its germination (review by Berner et al. 1995).

2.1.1 Striga and soil fertility

Several studies have shown that *Striga* infestation is correlated with low soil fertility and that improved soil fertility would lead to a reduction of the infestation (Lakoge et al., 1991; Weber et al., 1995; Ransom, 1999; Debrah et al., 1998). One of the weed's most contributing factors for development is low soil fertility and crop systems in SSA with no external inputs have contributed to decline of ditto (Cardoso et al., 2010). According to a study in Benin focus should only be on *Striga* management when soil fertility "exceeds a threshold value". Otherwise resources will be used without improvement in yields. (Abunewa and Padi, 2003).

Declining soil fertility has lead to the increase of *Striga* infestation due to the lack of nitrogen (N). N is said to have the effect of reducing strigolactone production from the host

plants and therefore also inhibit germination of *Striga* seeds. N also increases vegetative growth of the host plant, which strengthens it and protects the plant from *Striga* parasitism (Gacheru and Rao, 2011). When N has been applied to the crop, several studies indicate that *Striga* infestation is reduced and the crop yield increases (Sjögren et al., 2010). Total soil N content has showed to be negatively correlated with *Striga* seed density in the soil. Results have shown that both soil N and organic C is correlated with reduction of *Striga* seed density in the soil. With a low C:N ratio, *Striga* seed density is significantly lower in the soil than where the C:N ratio is high. However when the soil is highly degraded and infertile, application of N fertilizers seems to trigger *Striga*. Repeated use of N fertilizer would, however, most likely reduce the amount of *Striga* as the soil N content gradually increases (Schulz et al., 2002). In a study done in Western Kenya a higher fertilization input 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., 2010). Studies done on rice (*Oryza sativa*) (which also may be infected by *Striga*) shows that integrated soil fertility strategies which involves the use of legumes fixating nitrogen, little chemical, fertilizer and a *Striga* resistant genotype of rice prevent soil fertility degradation and improve rice productivity. In Western Africa higher rice production and weed suppression have been achieved by the use of nitrogen fixating legumes (Becker and Johnson 1998, 1999). Promiscuous soybeans in combination with mineral fertilizer (N) in maize have showed to increase the yield and provide sustainability in the cropping system. The study showed that promiscuous soybean cultivars significantly had higher dry matter and N accumulation in soils with low soil fertility. Soybeans have a large portion of underground biomass which releases nitrogen due to decomposition (Oikeh et al., 2008).

A good supply of N in the soil is a good way of *Striga* control. A study done by Ayongwa (2011) showed that roots with an increased N content led to a reduction of *Striga* germination. Moreover the study showed proof of a strong correlation between germination stimulants from the roots and the level of N in the roots. Different types of nitrogen fertilization suppress *Striga* either by the inhibition of *Striga* germination or the production of germination stimulants from the host plants. Chicken manure for an example delayed *Striga* emergence on sorghum but only at high rates. (Ayongwa, 2011). However Ikie et al. (2007) stated that urea had a greater effect on reduction of *Striga* emergence than chicken manure had, since it actually would lead to a higher emergence rate.

Some studies indicate that an increased use of fertilizer should not have a direct link to *Striga* control, though it has other benefits (review by Berner et al., 1995). Other studies indicate that direct application of phosphate would decrease the exudation of strigolactone and therefore reduce *Striga* germination and also *Striga* infection (Cardoso et al., 2010). However, the use of fertilizer is expensive and not an alternative to most farmers in Africa (Ransom, 2000).

2.1.2 Control methods

Striga has a high fecundity, it uses the host plants nutrients and the seed is asynchronous. These characteristics make the weed difficult to control (Andrianjaka et al., 2007; Worsham and Egley, 1990). The rate of infestation needs therefore to be managed through different control methods. Today there are several methods available when it comes to *Striga* control: soil preparation, hand-weeding, hoeing, herbicides, push-pull technology, resistant crop varieties, N-fertilization, biological control, germination stimulants and crop seed treatment. (Radi, 2007) However those who rely on synthetic compounds are not the best option. It is not sustainable and the farmers can hardly afford it. Techniques which include a changed cropping system are a sustainable solution which can ensure a proper yield (Abunyewa and

Padi, 2003). Today the most used control method against *Striga* is hand weeding. It is recommended to prevent seed set and seed dispersal. However this method has little impact to the present crop in the field and do not have a direct positive affect on the yield. It is a long-term improvement of controlling the weed by preventing an increase of *Striga*'s seed bank in the field. A study done in Cameron showed that when the farmer cannot see direct results it is not in their conception to do the weeding. (Ayongwa, 2010) A combination of host plant resistance, cropping practices, chemical and biological treatments is required. Improvement of fallow systems may also be a solution where trap crops are grown. However effective weed control in continuous maize cultivation could be just as good or a better fallowing in terms of controlling *Striga* (Andrianjaka et al., 2007; Pisanelli et al., 2008; review by Berner et al., 1995). Traditionally the fallow lasted for 8-12 years before the land once more was cropped for 2-4 years (Weber et al., 1995). By giving the crop a head start some prevention of *Striga* damage can be achieved. A study were pre-cultivated sorghum was used instead of direct-seeded sorghum a significantly reductions of emerged *Striga* was shown. (Review by Berner *et* al., 1995).

Plants can be resistant or tolerant towards *Striga*. These characteristics are considered to be the best weed control methods due to farmers' limitation in purchasing items. Many cereals are found to be naturally resistant to *Striga* e.g.; rice, sorghum (*Sorghum bicolor*) and some genotypes of maize. A resistant plant stimulates germination of *Striga* but it does not allow it to attach to the root. In *Striga* infested areas cultivation with resistant crops results in fewer *Striga* plants and higher crop yield than a non-resistant genotype of the cultivated plant would do (Rodenburg et al., 2006). A tolerant crop do not affect *Striga* in any way, however it has a higher stover, grain production and is less damaged than a non-tolerant crop (Kim, 1994). Trap crops induce germination of *Striga* seeds but do not host the parasitic weed and therefore result in suicidal germination since the seedlings die (Botanga et al., 2003). However, adoption of different control methods to reduce *Striga* infestation has been limited. The average farmer cannot afford external inputs or they do not consider it suitable in their cropping system (Ransom, 2000).

Push-pull is a cropping system where specific crops are intercropped and grown around e.g. maize to repulse and attract insects. The push crop grown in between the main crop repels insects from the field and the pull crop grown around the field attracts the insects. This technology was first developed to control steamborers but was later found to also suppress *Striga* weed in the field depending on which push component the main crop has been intercropped with. More than 30 000 smallholder farmers in East Africa have adopted the push-pull technology and their maize yields have increased from 1 tons per ha to 3.5 tons per ha. This technology improves the soil fertility and prevents soil erosion as well. According to a study done by Khan (2010), push-pull technology helps controlling both *Striga* and stemborers with at least 2 tons per hectare higher grain yield. Farmers in this study also reported improved soil fertility (Khan et al., 2010). Push-pull techniques – significantly reduced *Striga* emergence and from the second season stem borer were reduced. Soybean triggers suicidal germination of *Striga* and therefore reduces the *Striga* seed bank in the soil when intercropped with maize (De Groote et al., 2010). The efficient way of reducing *Striga* seed germination is the use on trap crops.

Desmodium spp., a legume with secondary metabolic compounds produces chemicals that repel stembores and allelopathic compounds which suppress *Striga*. It can be used for fodder or as green manure (Khan et al., 2002, Ladha et al., 1987) Used in push-pull technique it has increased the yields with almost the double in infested areas (Parker, 2008). A study done in the savannah zone of Ghana by Abunyewa (2003) gave a negative correlation between nitrogen content and *Striga* seed in the top soil (0-15cm). When legumes were

cultivated the number of *Striga* seed in the seed bank decreased from 28 183 seeds m^{-2} to 8 185 seeds per m^{-2}. However, when cereals were cultivated the number of seeds increased from 9 383 seeds m^{-2} to 16 696 seeds m^{-2}. Legumes can function as a trap crop since it induces germination of the *Striga* seed but do not allow it to attach and live of the root. Pure cereal cultivation also gave a 100 percent increase in *Striga* seed in the soil, while the legume cultivation decreased the *Striga* seed bank (Abunyewa and Padi, 2003). Desmodium has also been reported to have additional soil improvements such as; increasing of soil nitrogen, organic matter and conserving moisture (Khan et al. 2006).

Including fallow in the cropping systems with short duration species has shown to reduce *Striga* infestation since this species improves soil nitrogen status. Reduction of *Striga* has been proportional with the amount of biomass incorporated to the fields. When nitrogen was applied in improved fallow systems, cumulative maize yield increased from 15-28%. Improved fallow systems have a larger amount of biomass accumulated and a higher recycling of nitrogen than non-coppicing fallows. This means a more effective control of *Striga* and increased maize yield (Kiwia et al., 2009). However a study done by Abunyewa and Padi (2003) showed that traditional bush-fallow practices where land is cultivated until soil fertility is exhausted and then left for a long period where natural vegetation is established before cultivated again, does not control *Striga*. In the end of the fallow period there was still a high number of *Striga* seed in the soil (Abunyewa and Padi, 2003).

According to a study by De Groote (2010), crop rotation with maize-soybean and maize-crotalaria did not lead to a significant reduction in *Striga* seed bank, even though the maize yield was higher during the crop rotation. When fallows with *Sesbania*, member of the family *Fabaceae*, were included in the crop rotation, grain production of maize were higher in comparison with unfertilized continuous maize cropping (Sjögren, 2009).

In the United States, where problem with *Striga* is of great importance, a control program against *Striga* has been developed. It has four main objectives which are: 1) prevent *Striga* to enter the fields, 2) reduce the seed bank in the soil, 3) prevent *Striga* to reproduce, and 4) reduce crop losses. These objectives are aimed to be obtained through the use of *Striga* free planting material, crop rotation, transplanting, bio-control, host seed treatments and host-plant resistance (review by Berner et al., 1995).

2.1.3 Striga situation in Western Kenya

Western Kenya has a high population density and a majority of the inhabitants are poor (CountrySTAT Kenya, 2011). The estimated maize area in the *Striga*-prone area around Lake Victoria is about 246.000 ha. This area should provide about to 5.8 million people divided in 1.3 million households with sufficient amount of food (De Groote el al., 2008). Western Kenya's total area is 16.000 km^2 which gives a population density of about 363 people/km^2 (Kenya National Bureau of Statistics). Maize is the most important food and cash crop in this area (FAO, 2011a). The average maize consumption in this area is about 81 kg per person, 24 kg less than the estimated national consumption of 105 kg per person and year (Pingali, 2001). In Nyanza Province in Western Kenya, the average expected yield is 1.5t ha^{-1}. Moderately infested fields gave an average yield of 0.75 t ha^{-1}, which is about half, and fields with high *Striga* infestation only gave a yield about 20% of the average yield. When using seeds with herbicide treatment or resistant maize the yield was almost doubled (Parker, 2008). Studies have shown that farmers in western Kenya experience soil fertility and stembores as the major problems for low maize yields. (De Groote, Okuro, et al., 2004). In Siaya in western Kenya the farms are relatively large and the area is not as dense in population as in Vihiga and Bondo. In Vihiga, the farms are small and scattered (De Groote et al., 2010). The area studied in this work has traditional farming system with mixed crop-livestock and maize

as the major crop. Mean size of farms vary from 1 to 4 acres, the size is due to high population densities and inheritance division.

2.2 Soil fertility

High soil fertility can be given different characteristics. The soil should be rich in necessary plant nutrients and trace elements which also are in an available form for the plant. This is acquired when the soil has a pH between 6.0 and 6.8. Soil with high soil fertility also has a high content of soil organic matter (SOC) which helps to improve the structure in the soil and its capacity to retain water. A high range of microorganisms in the soil helps to support plant growth. Soils that are referred to have good soil fertility often also contain a large amount of topsoil. To measure soil fertility different methods and analyses can be conducted. To mention a few: CEC (Cation Exchange Capacity), WHC (water holding capacity) pH, Acidity, Soil texture, Humic Matter Percent (HM-%), Weight per Volume (W/V) and the amount of different nutrients and trace elements. (Eriksson et al., 2005)

2.2.1 Soil conditions in Western Kenya

In the studied area the represented soils are Nitisol and Ferralsols (Vanlauwe, 2011) according to FAO's USDA soil taxonomy (FAO, 2011b).

Nitisols are soils in the last stage of soil development (Eriksson et al., 2005), see Figure 3. Nitisols are found in highlands and steep slopes of volcanoes. Their origin is volcanic rocks and in comparison to other soils found in the tropics they have better chemical and physical properties such as CEC, SOC, WHC and aeration is good in these soils. (Gachene et al. 2003) However the high amount of oxides in the top soil glues the soil particles together and worsens thereby the soils physical properties (Eriksson, 2005). Because of natural leaching of soluble bases most nitisols have a pH <5.5 and are therefore often acidic. A low pH results in less nutrients and trace elements available for the crop. It also leads to toxic amounts of soluble Al in the soil. The clay content is often higher than 35%. (Gachene et al. 2003) The dominant clay mineral in Nitisols is kaolinit and it has an enrichment horizon for clay. (Eriksson, 2005). These soils are good for agriculture use and are intensely used for especially plantation crops e.g. banana, tea and coffee. To achieve optimal production fertilizer needs to be added. To prevent soil erosion of the top soil, which is a common problem, different soil conservations are required. (Gachene et al. 2003)

Figure 3. Nitisol. Source: ulrichschuler.net

Ferralsols are very old soils that are highly weathered and leached and have therefore poor soil fertility, see Figure 4. However this is restricted to the top soil. In the subsoil a low CEC occurs. These soils are found on undulating topography. There is always deficiency of P and N, while the Ferralsols are rich in Al and Fe. By the use of good agricultural practices the nutrients can be more equally distributed in the soil. These soils have good physical properties and have an excellent WHC. Just like Nitisols, these soils require fertilizers to maintain a high productivity. Ferralsols are used for a great variety of crops, both annuals and perennials, but are most suitable for tree crops. (Gachene et al. 2003)

Figure 4. Ferralsol. Source: World soil information.

2.3 Maize

Maize (*Zea mays L.*) is a staple crop in many countries in the world and is among other things grown for its energy-rich grains (starch-source) (Byerlee and Eicher, 1971). It belongs to the *Poaceae* family and is thereby a grass. It is also a C4 plant, annual, androgynous and cross-fertilizer. (Fogelfors, 2001) In West and Central Africa the crop continues to outcompete traditional crops. Maize has the potential of high yields, is relatively easy to cultivate, process, store and transport (Byerlee and Eicher, 1971). However maize has shallow roots which make it sensitive to drought and nutrient-deficient soils (De Barros, 2007**)**. Maize requires good water supply during flowering and are very sensitive for concurrent from weed during early stages of development. (Fogelfors, 2001) One of its major constraints is *Striga hermonthica* (Kim, 1991). Since maize is not native to Africa its resistance against the weed is poor (Buckler and Stevens, 2006). Maize cropped in soils with low soil fertility is more vulnerable to *Striga* than when it is cropped in soil with a good fertility status (Badu-Apraku et al., 2010a).

2.3.1 IR-Maize

Maize consists of different traits that favor *Striga* differently. Many studies have been done to find these traits and to create resistant maize breeds (Badu-Apraku et al., 2010b). *Striga* resistance is the ability of the host root to stimulate *Striga* germination but at the same time prevent attachment of the seedlings to its roots or to kill the seedlings when attached (Kim, 1994). When screening for *Striga* resistance the most important traits are host plant damage, few *Striga* plants attached to the crop plant and high grain yield (Badu-Aprakuet et al., 1999). The rate of *Striga* damage is an index of tolerance while emerged *Striga* is an index of resistance (Rao, 1985). IR-maize (Imazapyr resistant maize) is coated with the herbicide imidazolinone. The roots of maize will first absorb the herbicide which it is resistant against and then later release it as it kills *Striga* seedling and seeds (Kanampiu et al., 2002). Imazapyr is absorbed quickly through plant tissue and can be taken up by roots. IR-maize is used as a control method against *Striga* and to improve the yields in *Striga* infested areas. Studies have

shown that traditional mono-cropping with no use of fertilizer, IR-maize increased the yields compared to the use of local varieties from 0.5 tons per hectares to 1.0 tons per hectares. However, compared with average yields in the studied area the yield with IR-maize is still low. A study in Western Kenya has showed that the use of IR-maize reduces and delays the emergence of *Striga* which lead to a reduced seed bank (De Groote et al, 2009).

3. MATERIAL AND METHODS

In this study 120 farmers from three districts (40 farmers per district) in western Kenya participated. The work took place during January-June 2011 after the short rain season and during the long rain season. The study consisted of five parts:

1. *Mapping and interviewing.* The household head or their spouse was interviewed; two fields with low respectively high soil fertility where maize or other cereals commonly were grown were identified.

2. *Soil sampling collection*. Soil were sampled and collected from the identified fields with high and low soil fertility respectively.

3. *Soil analysis*. Chemical and physical parameters were analyzed to investigate correlations between *Striga* prevalence and soil fertility. Seed bank density of *Striga* was also analyzed.

4. *Quantitative mapping of Striga*. To get *Striga* prevalence in the field, trials were set up where *Striga* was counted after emerging: 6-8-10 weeks after maize in the trials had been planted.

5. *Feedback to farmers*. Feedback was given to the farmers through a follow-up field visit.

3.1 Sites

All studied sites were located in Western Kenya where crop yields usually are low and *Striga* infestation is prominent (De Groote et al., 2008). Three districts, Siaya (S: 0° -5' 0, E: 34° 15' 0), Bondo (N: 0° 14' 19", E: 34° 16' 10") and Vihiga (N: 0° 1' 60, E: 34° 43' 0), see figure 5, with two sub-locations each (except Bondo which had three, see further *Farmer Selection*), were included in the study. The sub-locations were: Sega and Nyabeda in Siaya, Abom, Ajigo and Bar-Kowino in Bondo and Munoywa and Bukulunya in Vihiga district. These sites all had two cropping seasons annually, short rains from September to January and long rain from March to July. The accumulated rainfall is about 700 mm/year at the lakeside and 1800 mm/year at the highest points farther in from the lakeshore. The mean temperature is 22 degrees Celsius, while the average minimum and maximum temperature are

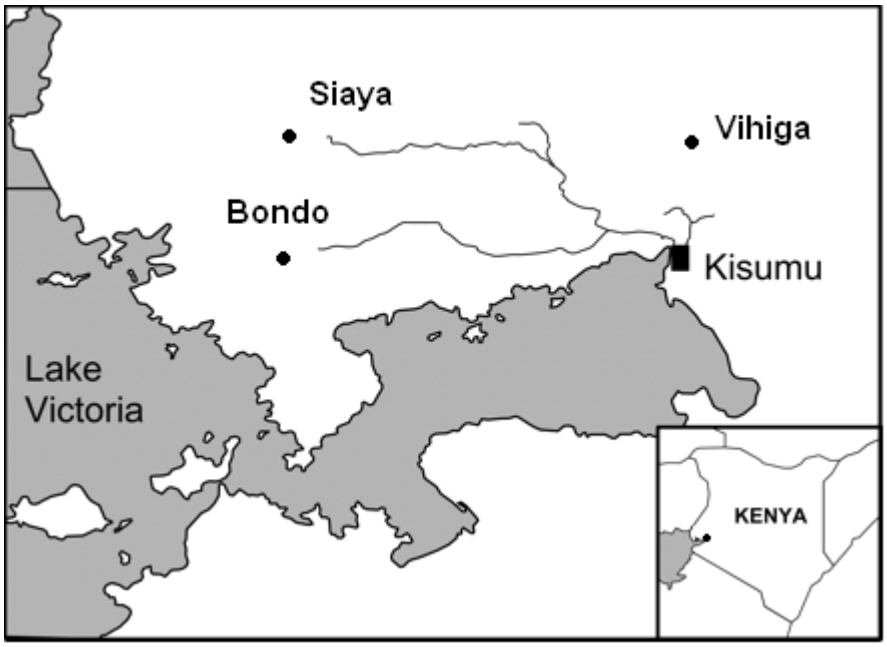


Figure 5. Western Kenya with the three districts Bondo, Siaya and Vihiga.

13 and 30 degrees Celsius respectively. Soil types in this area are mainly nitisols and ferralsols (Vanlauwe, 2011) which are clay and sandy loam with low soil fertility status (Jaetzold and Schmidt, 1982).

3.2 Farmer selection

Originally 20 farmers from each sub-location were supposed to be represented, giving a total number of 120 farmers participating in the study. However due to a misunderstanding one pair of enumerators chose 14 farmers from one sub-location and 6 from another, instead of a total number of 20 farmers from one sub-location. This meant that another sub-location was added in Bondo district. However the farming and agronomic knowledge can be regarded to be equal in these two sub-locations since they only was separated by a road and belonged to the same farmer association group. Farmers in each sub-location were partly randomly selected. The major factors for including them were their willingness in participating in the study and previous experience of working with researchers.

3.3 Field selection

Two fields from each farmer where cereals normally are cropped were identified by the farmers, one with low soil fertility and one with high soil fertility. In total, 240 fields were identified and sampled. In Bondo two farms had only one big field. The field was then divided in one good (high) part and one bad (low) part to reach a total number of 240 fields. Fertility status was in relation to existing soil fertility on the farm and not in relation to other farmers' fields and fertility status. The identification of the fields was done by the use of the questionnaire section B7, see Appendix 9.5. For every identified field specific field data were collected according to the farmers' perception of the field. Out of all 120 farmers, initially 11 farmers from each district where chosen for the trial set-ups (see section *3.4.3 Field Trial – Striga Germination*).

3.4 Data collection

Nine enumerators were selected by their origin and knowledge of the local tribe languages in western Kenya. Some had been doing surveys before while others were doing it for the first time. A training day was held to educate the enumerators how to perform the interviews. The enumerators were then paired and given one sub-location each. One sub-location in Vihiga was mannered together by all enumerators during one day.

3.4.1 Interview

All selected farmers were first interviewed, by the use of a structured questionnaire; see appendix 9.5, made by the use of previous questionnaires for *Striga* studies and wealth factors in Western Kenya (AATF / TSBF-CIAT Project – A Perception Study of *Striga* Control using IR-Maize Technology in Western Kenya – Household Survey Questionnaire; Cialca – TSBF-CIAT Legume Project Farming Systems, Market Access and Nutrition/Health Final Characterization Study; N2Africa Baseline Survey – Farm households (Rapid farming system characterization). The interviews were conducted during two weeks, from the end of January to the beginning of February. The questionnaires consisted of 1) introduction with household characteristics, 2) farm description, 3) *Striga* knowledge and 4) specific field description; low

and high soil fertility. Under the first section, a sketch of the farm was drawn, an example of a farm sketch can be found under appendix 9.4. The aims of the questionnaires were to evaluate which major factors that could have been contributing to *Striga* prevalence in different fields on the farm (maize production, input use, intercropping history, manure, fodder, etc.). When returning for the soil sampling additional questions were asked and clarifications were made if needed.

3.4.2 Soil sampling

Soil sampling was conducted from the identified plots on the farm. Farmers with only one field as for Bondo, soil were sampled from the sections with best (high) respectively worst soil (low) fertility. The sampled soil was used for determination of *Striga* seed bank and soil fertility status. Following factors were measured: pH, tot C, total N, available P, texture and seed bank of *Striga*. By the use of a soil auger (internal diameter 5cm), at a depth of 0-15 cm, 10 subsamples equally divided on a W shape in the field were collected, see Figure 6 and 7. The subsamples were then bulked together to one composite sample. Approximately 1 kg of the soil was then put in a plastic bag and labeled. Later at the local TSBF office in Maseno, the soils were air-dried and then sent for seed bank and soil fertility analyses. The soil was sampled in Vihiga and Siaya district in beginning of March and in Bondo district in mid-March. Due to drought, the soil sampling could not be carried out earlier or at the same time. Analysis of C and N were conducted through IR-analysis (see appendix 9.1.1) plus 10% of IR-samples for C and N was done by wet chemistry. pH and Olsen-P analysis were also carried out through wet chemistry (see appendix 9.1.2) Texture analysis where done by TSBF staff using hydrometer method (method description see appendix 9.1.3) where sand was greater than 53 µm, silt less than 53µm and greater than 2µm and clay less than 2µm. Seed bank analysis was done at KARI (Kenya Agricultural Research Institute) at Kibos center, using 250g soil through elutriation method (see appendix 9.1.4).

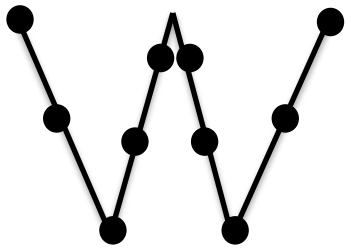


Figure 6. Sketch on how the soil was collected in the fields.

Figure 7. Soil sampling in the field by the use of a soil auger.

3.4.3 Field trial – Striga germination

The relationship between soil fertility status and *Striga* prevalence was studied by installing field trials on the identified fields. Initially, trials were supposed to be installed in all three districts. However, due to lack of rainfall, germination of IR-maize was poor in Bondo district. In Vihiga district the farmers had already planted on the identified fields and were not willing to uproot their crops because of the planned trials. Therefore Bondo and Vihiga district were excluded from the study. In Siaya 11 trials were set up with a plot size of 6mx6m and consisted of IR-maize and local maize, both with and without fertilizer application, see Figure 8. The fertilized plots got 450g DAP (Diammonium phosphate) along the planting furrows. 8 weeks after planting the fertilized fields were top dressed at a rate of 1 bag (90 kg) per hectare. Maize was planted at a distance of 25 cm within the row and 75 cm between the rows.

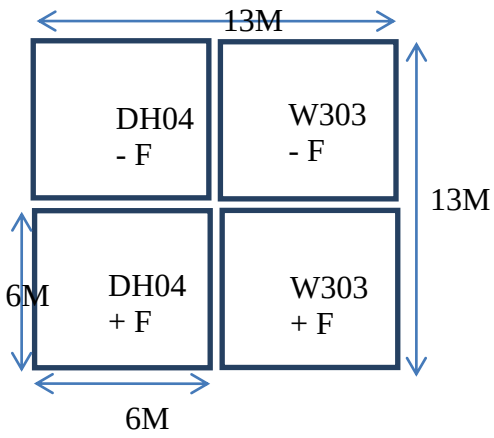


Figure 8. Sketch of trial and its treatments. DH04 is a local maize breed in Kenya and W303 is IR-maize, resistant to *Striga*. Both types of maize were treated with fertilizer and no fertilizer.

DH04 is a local maize variety distributed by the Kenya seed company. It has relatively short period for development, 100-120 days and are suitable in altitudes around 800-1200m (kenyaseed.com, 2010). W303 is an IR-maize species coated with imidazolinone which kills *Striga* seeds and seedlings. The plots were not planted until 4th and 5th of April due to lack of rain. 6, 8 and 10 weeks after planting emerged *Striga* plants were counted in the plots, see Figure 9. After every count *Striga* were uprooted and removed from the field. Plots were managed by local staff of TSBF and the farmers. Maize growth, *Striga* germination and maize yield was measured in all trials with the net plot size of 22.5m (4.5mx5m).

Figure 9. Local maize in field trial in Nyabeda. *Striga* germination is seen. Photo: Miriam Larsson.

3.5 Data analyses

Data was analyzed by the use of statistical software program Minitab 16. For both *Striga* emergence count in field and for *Striga* seed bank analysis, the logged values for *Striga* were used, this due to the many cells containing zero. Missing values for *Striga* seed bank were removed in pairs, e.g. one value was missing for field with high soil fertility then the value for the low soil fertility field was also removed.

Correlation and an analysis of variance between district, sub-location, farm level and field level were analyzed through GLM (general linear model). Both with field nested within the farm (*Seed bank = District Sub-location(District) Farm (District Sub-location) Field (District Sub-location Farm)*) and with field not nested within farm (*Seed bank = District Sub-location(District) Farm (District Sub-location) Field (District)*).

Regression analysis was used to evaluate any likely correlations between *Striga* seed bank and pH, ohlsen-P, C, N, clay, silt, and sand. Each soil valuable was analyzed towards *Striga* seed bank through single regression analysis:

Seed bank = pH, ohlsen-P, totC, totN, Clay, Sand, Silt

A multiple regression analysis for *Striga* seed bank was also done:

Seed bank = pH ohlsen-P totC totN Clay Sand Silt

A correlation analysis of C:N ratio and pH where performed with pH and C:N ratio as variables.

Striga emergence in field trials was analyzed through variance analysis both with field nested within the farm and field not nested within the farm. In both models farm was indicated as a random factor. Fully nested design:

*Emergence = Farm Field(Farm) Variety Fertilization Fertilization*Variety*

*Yield = Farm Field(Farm) Variety Fertilization Fertilization*Variety*

Field not nested within farm:
*Emergence = Farm Field Variety Fertilization Fertilization*Variety*

*Yield = Farm Field Variety Fertilization Fertilization*Variety.*

Maize plant stand regarding variety and fertilizer was analyzed through a fully nested analysis of variance. Farm was indicated as a random factor. A second analysis of variance was performed where field was not nested within the farm:

*Plant density = Farm Field(Farm) Variety Fertilizer Variety*Fertilizer*

*Plant density = Farm Field Variety Fertilizer Variety*Fertilizer*

To evaluate the farmers' perception on *Striga* infestation ratio, a regression analysis was performed. *Farmer estimation (none=0, little=1, medium=2, high=3) = Striga seed bank*.

Striga emergence and *Striga* seed bank in the trials were analyzed through a regression analysis (*Striga emergence = Striga seed bank*) for both local maize and IR-maize where no fertilizer had been added.

3.6 Feedback

After the survey was conducted and some of the results were achieved feedback was given to the farmers. Feedback was given one time in each sub-location where the farmers participating in the study had gathered, most often at the place for the local farmer association groups. Farmers were informed what the soil sampled from their fields had been used for and which results so far had been analyzed. But also which reaming analyses that was supposed to be conducted. The farmers could share their thoughts and questions about the *Striga* situation in the specific sub-location and on their farms.

4. RESULTS

The results for each district have been summed since the sub-locations were chosen to get an even distribution of farmer selection within the districts but are regarded as equal due to geographic location and farmer practices and knowledge.

4.1 Farmer assets and management history

Data presented in this section are summaries of information obtained from the questionnaires, *see appendix 9.5.* No statistical analysis has been performed and average values at district level will be presented in tables and figures.

4.1.1 Household characterization

In total there were 54 female and 66 male household heads participating in the study, i.e. a total of 120 households. The gender distribution of the household head in each district is presented in Table 1. The distribution between male and females were quite equally divided in all districts. If the household heads spouse was the one answering the questionnaire the summed answers are still regarding the household head (age, gender, level of participating on the farm etc.) and not the interviewed spouse.

Table 1. Distribution of gender in the studied area.

District	Female	Male
	[%]	
Vihiga	45	55
Siaya	47.5	52.5
Bondo	45	55

The household head were asked to indicate the level of completed school education. In Table 2 a summary can be seen of how many of the farmers have completed primary school or corresponding schooling. The table only indicates if the household head has completed any form of schooling, it does not indicate if higher schooling has been achieved. The lowest level of completed school was in Bondo, were 47.5% of the farmers had completed at least primary school. The average family size is also indicated in Table 2. Average family size did not vary that much with 4.7 persons per family in Vihiga to 5.2 persons per family in Bondo. Family composition only indicates the total family number, i.e. even family members not living on the farm and not the actual number of persons living in and being supported by the household.

Table 2. Family member in each household and percentage of completed schooling-level (at lest primary school).

District	Schooling level	Family member
	[%]	[no./household]
Vihiga	90	4.7 (2.3, n=40)
Siaya	72.5	5.2 (3.0, n=40)
Bondo	47.5	4.8 (2.0, n=40)

Most household heads worked fulltime on the farms. In all district farmers had other sources of income than farming at the own farm. In Table 3 the average income rank from the own farm is presented. In Siaya where all farmers except one indicated that they work

fulltime on the farm, other sources of income also existed. However, this income was not necessarily from the household head him-/herself.

Table 3. Farm income originated from the own farm and the household head participating in fulltime work on the farm.

District	Fulltime rank	Farm income
	[%]	
Vihiga	92.5	64.5 (27, n=40)
Siaya	97.5	88.5 (15, n=40)
Bondo	90	80 (17, n=40)

The smallest farms were found in Bondo, with an average size of 0.9 acre followed by Vihiga with 1.1 acre and Siaya with 2.3 acre. (Farm sizes were estimated by enumerators when farmers did not know it themselves). Both farm size and TLU (Tropical Livestock Unit) are presented in Table 4. The biggest farms also had the highest TLU number and the smallest farms had the lowest number of TLU.

Table 4. Farm size and TLU

District	Farm Size	TLU*
	[hectares]	[TLU/farm]
Vihiga	1.1 (0.8, n=40)	1.5 (1.05, n=40
Siaya	2.1 (1.3, n=40)	2.3 (2.04, n=40)
Bondo	0.9 (1.2, n=40)	1.5 (2.19, n=40)

*** TLU = Tropical Livestock Unit (cattle=0.7, sheep or goat=0.1, pig=0.2 and chicken=0.01), unit 1 TLU.**

Farmers were asked to indicate if they purchased any inputs to the farm such as; seeds, fertilizer, manure, fodder and pesticides. Since the credibility of how much the farmers actually bought were low, this due to lack of correlation when crosschecking the answers in the questionnaire and no following up on that. The results have therefore been translated in to whether they bought it or not (Y/N) and not the amount they bought. Almost no farms bought fodder, only five farmers in Vihiga district (Table 5). The same went for pesticides, in Vihiga nine farmers sometimes bought pesticides and three farmers in Siaya district. In Bondo no farmers at all bought pesticides. About half of all farmers participating in this study bought seeds for planting, equally divided on the sub-locations. Except in Bondo most farmers normally bought fertilizer and in all districts the purchasing of manure was low. See table 5.

Table 5. Purchased inputs in percentage to the farm in all districts

District	Seeds	Fertilizer	Manure	Fodder	Pesticides
			[%]		
Vihiga	57.5	85	12.5	12.5	22.5
Siaya	42.5	67.5	30	0	7.5
Bondo	57.5	30	17.5	0	0

4.1.2 Farm description

Almost all farmers owned the land they cultivated. Three farmers in Siaya district rented one field each. Five farmers in Bondo district rented fields; three of them rented two fields and the other two rented one field each. They all used the rented field for planting maize.

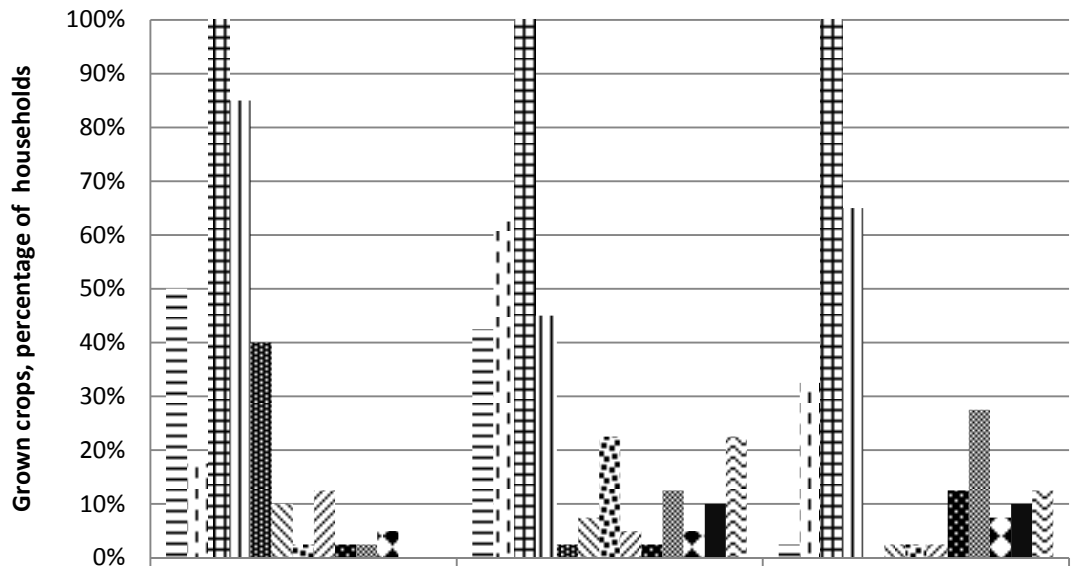
In both Vihiga and Siaya 35% of the farmers let their animals graze on at least one of their fields after harvesting. In Bondo however 90% of the farmers allowed grazing on the fields.

Farmers were asked to indicate whether they practice crop rotation or not on their farm. Farmers who practice crop rotation on one or more fields, were maize or other cereal normally are cultivated, ranged from 50-80%, see Table 6. The lowest percentage of crop rotation was found in Siaya district were only about half of the farmers in practiced crop rotation.

Table 6. The use of crop rotation on one or more field on the farms.

District	Crop Rotation on fields [%]
Vihiga	77.5
Siaya	50
Bondo	80

In all district the most commonly grown crops were maize (*Zea mays* L.), cassava (*Manihot esculenta* L.), beans (*Phaseolus vulgaris* L.) and bananas (*Musa acuminata* L) (Figure 10). Variations between the different districts can be seen in Figure 10. In Siaya for example, 23% of the farmers grow Irish potatoes (*Solanum tuberosum* L.) but this crop was rarely cultivated in the other districts.



	Vihiga	Siaya	Bondo
Bananas	50%	43%	3%
Cassava	18%	63%	33%
Maize	100%	100%	100%
Beans	85%	45%	65%
Napier grass	40%	3%	0%
Vegetables	10%	8%	3%
Irish potaoes	3%	23%	3%
Sugarcane	13%	5%	3%
Millet	3%	3%	13%
Sorghum	3%	13%	28%
Soybeans	5%	5%	8%
Sweet- potaotes	0%	10%	10%
Groundnuts	0%	23%	13%

Figure 10. Crops grown in all districts.

4.1.3 Farmer knowledge on Striga

When farmer were asked to estimate the *Striga* pressure on their fields almost all farmers in all three district estimated that they within the farm had the range from no *Striga* to high *Striga* pressure. Only three farmers, two in Vihiga and one in Bondo claimed not to have any *Striga* at all on their fields.

According to farmers' estimation *Striga* infestation was highest in Bondo where almost all farmers estimated it to be a big problem (Table 7 and appendix 9.2). Farmers in Siaya also estimated a high level of *Striga* infestation, however slightly less than the farmers in Bondo. Farmers in Vihiga estimated that the fields were medium infested with *Striga* or that they had little to no *Striga* in the fields. In both Bondo and Siaya district most farmers experienced an increase of *Striga* since the first time they noticed it. In Vihiga, on the other hand many farmers indicated that they did not have an increase of *Striga* anymore. Many farmers in Vihiga indicated that *Striga* had decreased recently and therefore the percentage of fields with *Striga* had declined. Most farmers have had *Striga* on the farm for quite some time. The

lowest estimated years were reported from Bondo with only 6 years in average, see Table 7. For detailed data of years with *Striga* on the farm see Appendix 9.2.

Table 7. Farmer estimation of *Striga* presence (no of years), expansion and infestation ratio on the farm.

	Striga presence	*Striga* expansion	*Striga* infestation
District	[no. of years]	[% yes/no]	
Vihiga	14.5 (13.9, n=40)	25	35
Siaya	12 (11.5, n=40)	87.5	50
Bondo	6 (6, n=40)	83	70

Based on the interviews, fields furthest from the homestead had the highest infection rates of *Striga* in Vihiga district. In Bondo it was equally distributed between fields near the house and those furthest away. In Siaya district fields near the house had most *Striga*. see Figure 11.

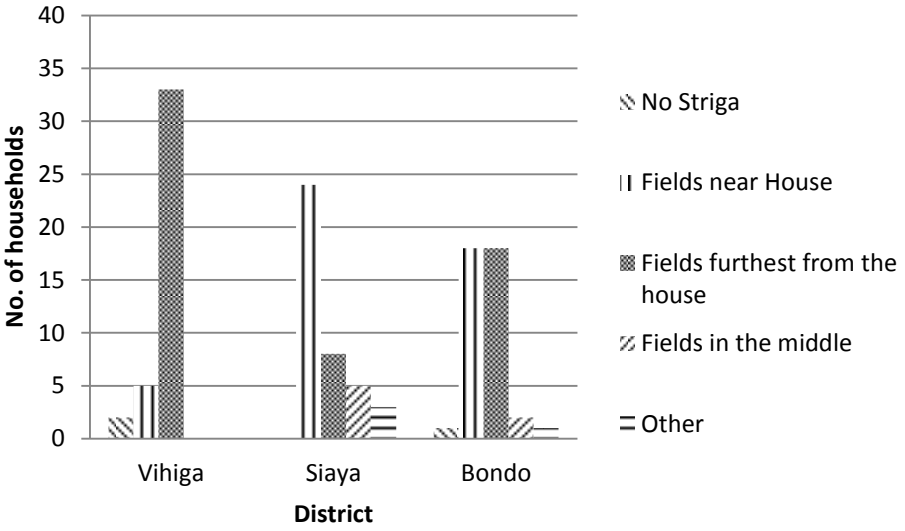


Figure 11. Farmer indication on which fields had most *Striga* depending on its location.

All farmers indicated whether they practiced any control methods against *Striga* or not, see Figure 12. The most common used methods were the traditional ones such as the use of manure (to increase the amount of N in the soil), uprooting, uprooting and burning or uprooting and removal from the field. Only a few were using modern technologies such as Imazapyr (herbicide), Resistant (IR) - Maize variety, *Striga*-resistant maize (KSTP 94), *Striga*-resistant maize (WS 909), *Striga* resistant maize (KSTP 94) grown with legumes, *Striga*-resistant maize (WS 909) grown with legumes, intercropping of legumes followed by cassava/Desmodium (Maize in the 3rd year) and Push-pull (Maize-Desmodium strip cropping). Most farmers practiced some form of control method and only a few did not practice any control method at all. The two farmers in Vihiga district that did not practice any control methods indicated that they did not have any *Striga* on the farm and therefore had no need to control it any more. Farmers in Siaya who indicated no use of any control methods however indicated that *Striga* was present on the farm. In total only 16 out of the 120 farmers did not use any form of control methods at all. Six farmers in Bondo intercropped with legumes which then where followed by cassava or desmodium, one farmer in Siaya and two farmers in Vihiga used push-pull technology. In total 21 of the farmers used some form of modern technology.

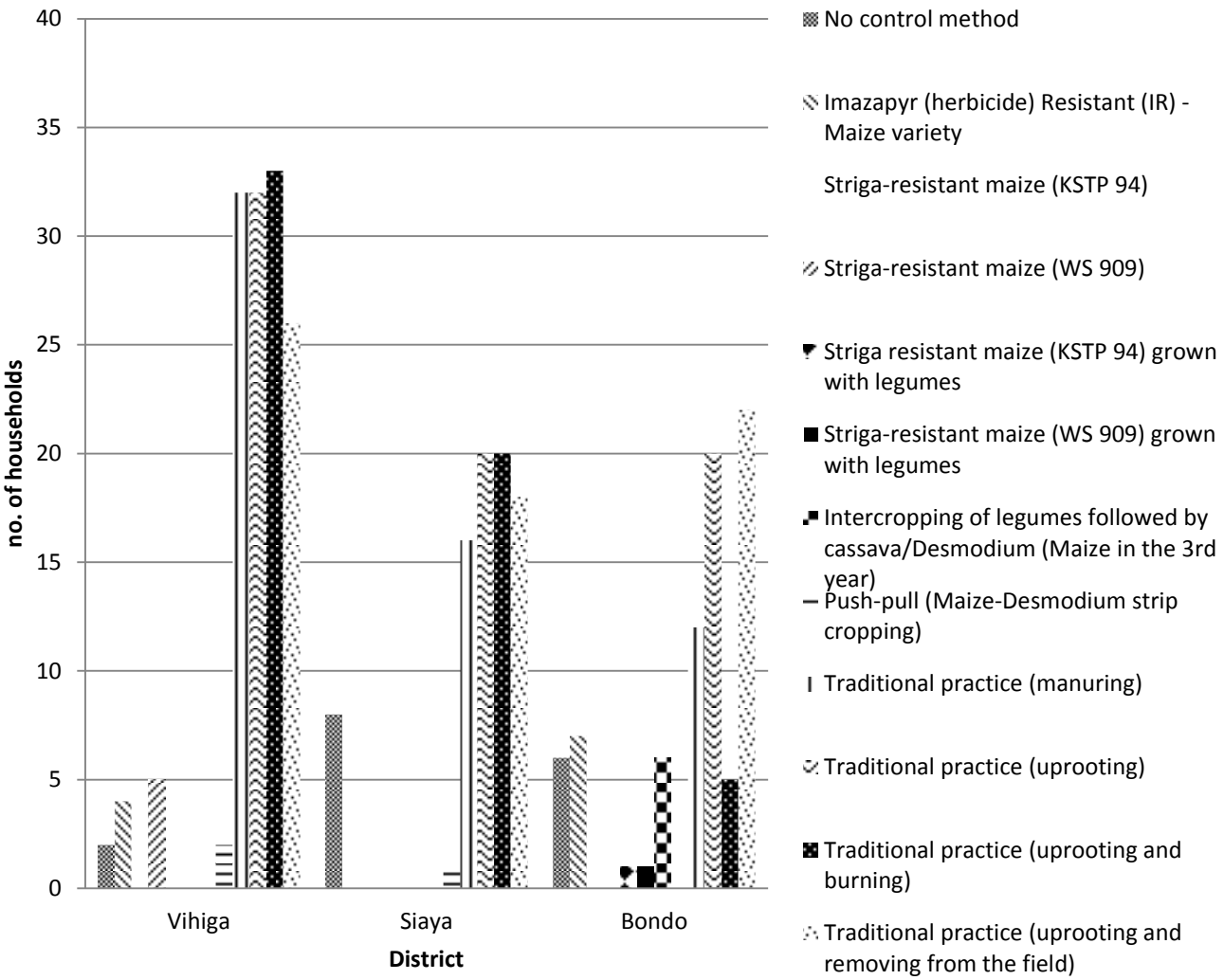


Figure 12. Practised control methods on the farms. Standard error.

Farmers who had not yet adopted any modern technology were asked to indicate why not. The main reason to why farmers had not adopted any modern technology for *Striga* control was because they wanted to gather more information about the technology first (Figure 13). 16 farmers indicated that they were not aware of any modern technology. Ten farmers thought traditional practices were better and 33 farmers said it were cash constraint that was the reason for no adoption of any modern *Striga* control methods. The different reasons for no adoption are presented in Figure 13.

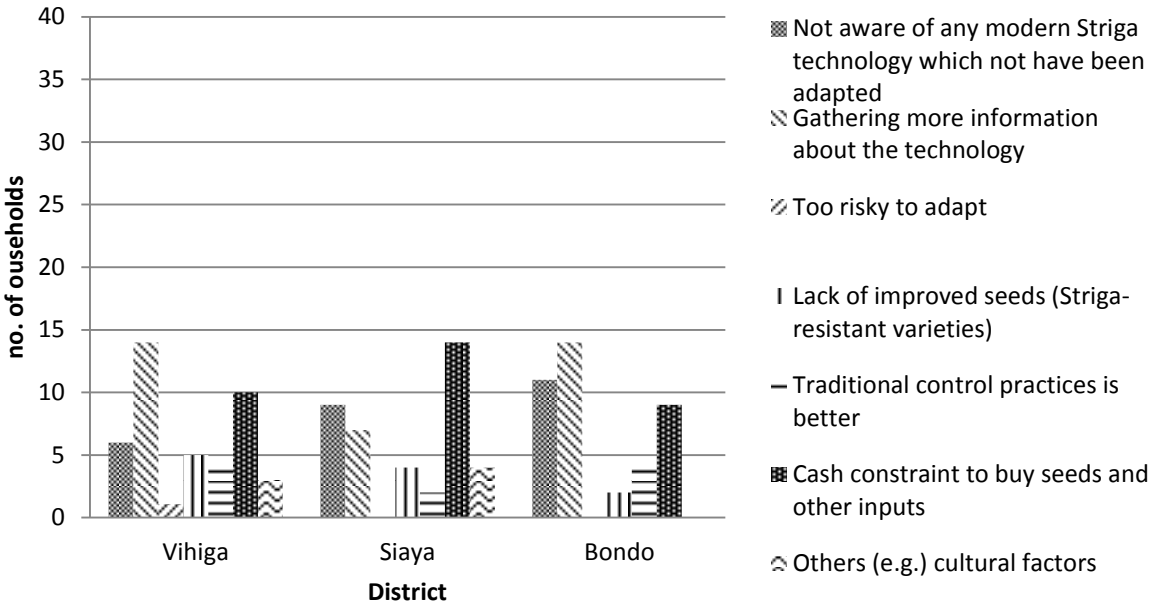


Figure 13. Reasons for no adoption of modern technology for *Striga* control.

4.1.4 Identified field properties

Most of the identified fields (high and low soil fertility) were attached to the homestead. However in Bondo a higher percentage of the fields were detached, i.e. not located near or connected to the homestead, Figure 14.

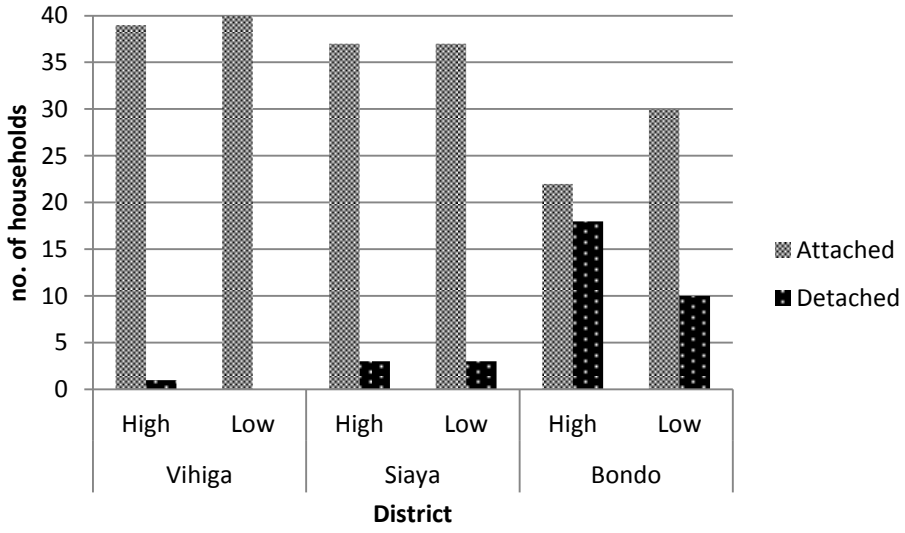
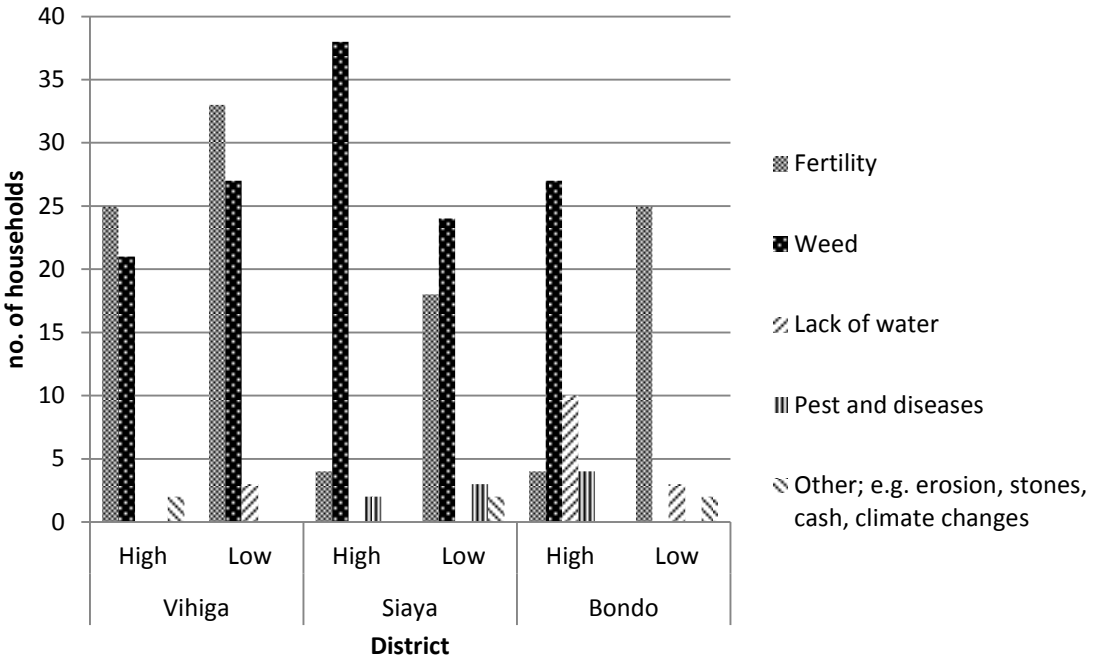


Figure 14. Field location regarding to position of homestead.

A summary of the farmers' estimated main crop constraint on both fields is presented in Figure 15. For fields with low soil fertility, according to the farmers, fertility is indicated as the main crop constraint except for Siaya where weed is indicated as the main crop constraint. For fields with high soil fertility weed is the most common crop constraint. In Bondo, which is a dryer area, many farmers indicated lack of rain as the main crop constraint. In Vihiga, fertility status is indicated as the main crop constraint even in fields indicated as high soil

fertility. Many farmers answered with more than one crop constraint, most often both weed and fertility were given as an answer. Therefore the numbers of crop constraint are not comparable between the districts since the summed values exceed 20 constraints. *Striga* is assumed to be included in weed.

Pesticides were only used on 7 out of the 240 identified fields, 1 field in Vihiga and 6 fields in Siaya.



Land preparation on the identified fields differed between the districts (Figure 16). In

Figure 15. Main crop constraint on the farms. However a number of farmers choose to indicate two constraints since they could not tell which one was the major one, most often both fertility and weed. Therefore, the total number of crop constrain from each district is not 20.

Vihiga the fields were only hoe-tilled and 7 fields were indicated not be prepared at all. In Bondo ploughing the fields were quite common. Some farmers indicated that they both ploughed and hoe-tilled the land. One farmer in Bondo used a tractor for ploughing his high fertility field.

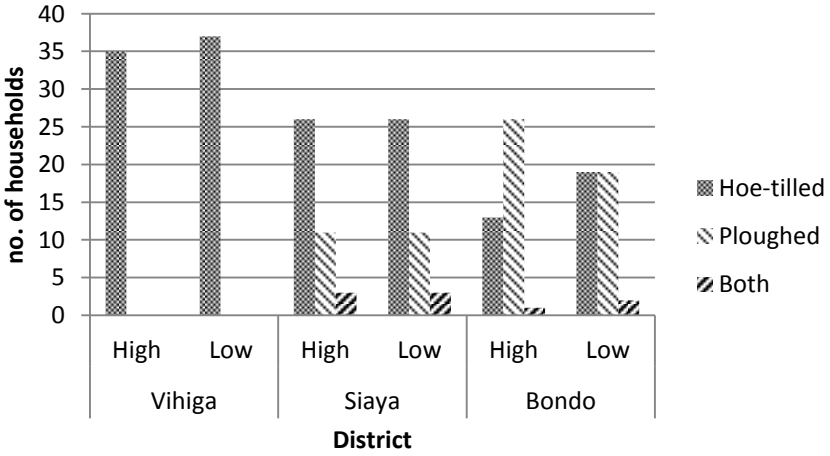


Figure 16. Land preparation on the identified fields.

Farmers were asked to indicate what kind of inputs they add to the fields (Figure 17). In Vihiga most farmers used both fertilizer and organic material on their fields, only one low fertility field did not get any input. In Bondo, 18 out of 40 low fertility fields and 17 out of 40 high fertility fields did not get any form of input at all. See Figure 17.

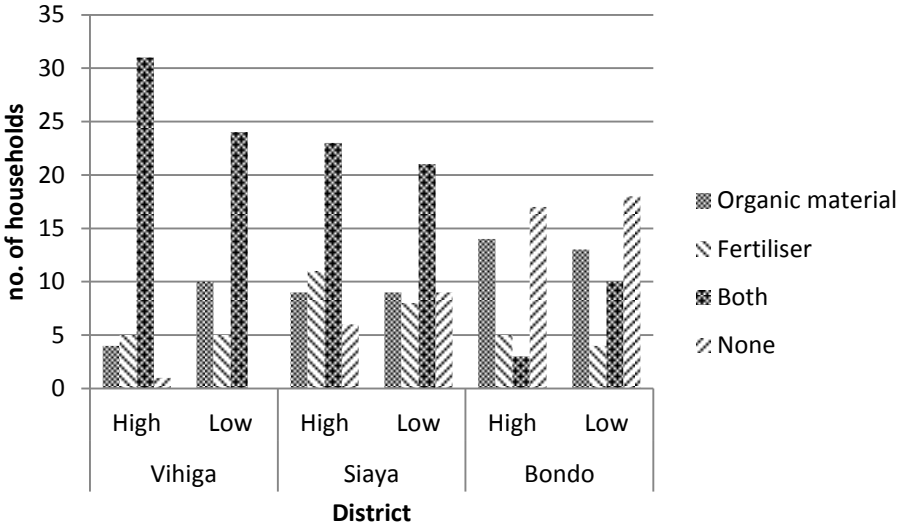


Figure 17. Utilization of inputs on the identified fields.

Organic material e.g. compost or manure, and fertilizer were added to the fields in different ways (Figure 18). They were either point placed, broadcasted, banded in or near the line or broadcasted and incorporated. Almost all fertilizer were point placed, a few were banded in or near the line and only two fields, one low and one high in Vihiga were broadcasted and incorporated. See figure 18.

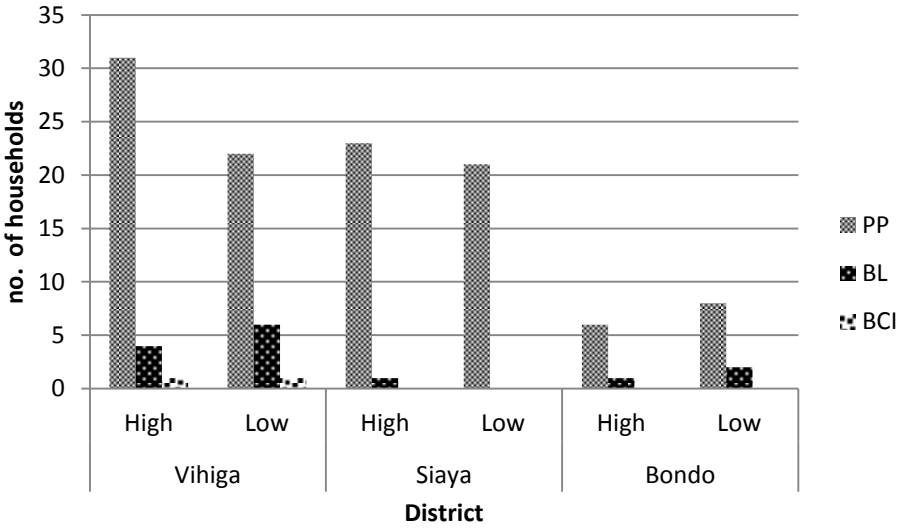


Figure 18. Methods of application of fertilizer on the identified fields. PP = Point-placed, BL = Banded in or near the line, BCI = Broadcasted and incorporated.

The manner of application for organic material varied more than for fertilizer (Figure 19). In Vihiga all four methods (point placed, broadcasted, banded in or near the line,

broadcasted and incorporated) were commonly used. In Siaya point placed and broadcasted dominated and in Bondo point placed were the most dominated one.

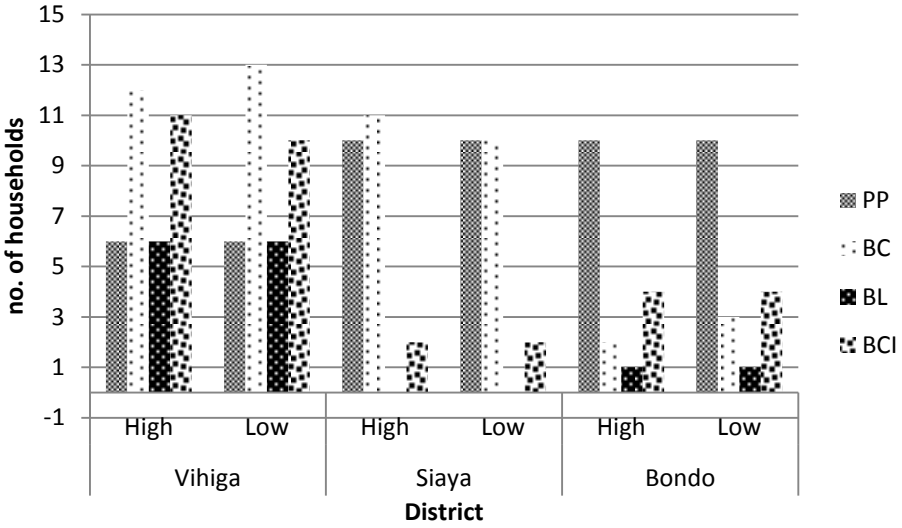


Figure 19. Methods of application of organic material on the identified fields. PP = Point-placed, BC = Broadcasted, BL = Banded in or near the Line, BCI = Broadcasted and Incorporated.

Water can be harvested on the fields and farmers were to indicate if they practice any of the techniques for collection of water in the field on the identified fields. Except for Vihiga, on most fields there was no water harvesting techniques practiced. In Vihiga the most common water harvesting techniques were planting pits followed by ridges, tied ridges and last half moons. In both Siaya and Bondo ridges were more commonly used. Half moons were only practiced by 2 farmers, one in Vihiga and one in Siaya, see Table 8.

Table 8. Water harvesting techniques on the identified fields.

District	Field	None	Planting pits	Ridges	Tied ridges	Half moons
		[no. of households]				
Vihiga	High	15	14	6	4	1
	Low	16	16	4	4	-
Siaya	High	30	-	5	4	1
	Low	29	-	7	3	-
Bondo	High	34	1	5	-	-
	Low	30	2	8	-	-

Erosion can be prevented by the use of conservation structures, either structural or by vegetation. In Vihiga most farmers used some form of conservation structures. About half of the farmers in Siaya and most farmers in Bondo did not practice the use of a conservation structure, Figure 20.

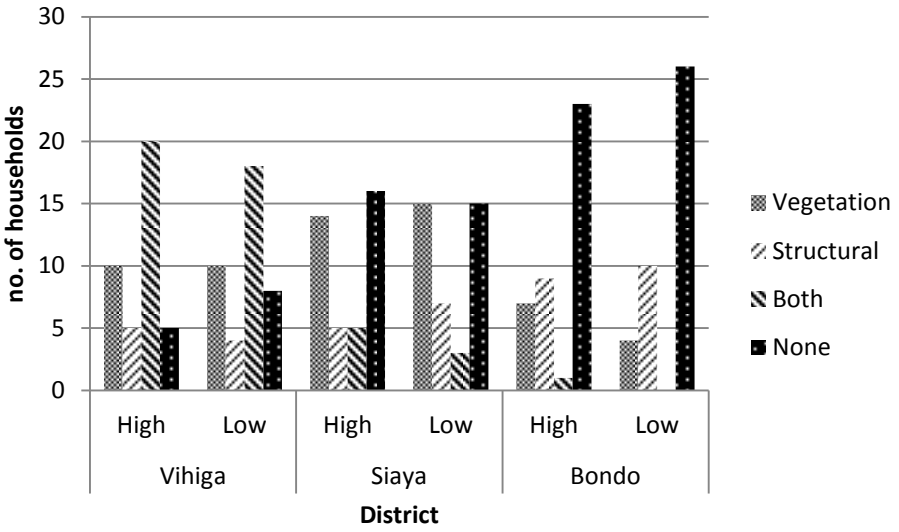


Figure 20. The use/presence of conservation structures on the identified fields.

4.2 Soil fertility and Striga seed bank

All soil variables pH, ohlsen-P, clay %, silt %, sand %, TotC % and TotN % were tested as predictors for *Striga* seed bank (see Table 9). No average values were used in the regression analysis.

Table 9. Average values of soil variables from sampled soil from fields with high and low nutrient status in three districts (Vihiga, Siaya and Bondo) and stdev, n=40

District	Field status	Ohlsen-P	pH	totC	totN	Clay	Sand	Silt
		[mg/kg]				[%]		
Vihiga	High	11.36	5.81	1.82	0.18	35.2	51.3	13.4
		(9.49)*	(0.33)	(0.24)	(0.02)	(4.9)	(4.5)	(2.3)
	Low	10.29	5.73	1.81	0.17	37	50.3	12.7
		(16.71)	(0.34)	(0.20)	(0.02)	(5.1)	(4.8)	(2.4)
Siaya	High	4.25	5.63	1.75	0.13	30.1	60.5	9.4
		(3.40)	(0.41)	(0.57)	(0.05)	(7.7)	(11,1)	(4.6)
	Low	6.51	5.61	1.71	0.13	30.6	59.6	9.8
		(11.37)	(0.46)	(0.68)	(0.05)	(7.0)	(11.1)	(4.7)
Bondo	High	13.26	6.33	1.98	0.15	32.7	53.3	14.0
		(21.28)	(0.46)	(0.52)	(0.04)	(5.3)*	(5.4)*	(2.6)*
	Low	6.21	6.21	1.85	0.14	30.8	54.8	14.4
		(21.03)	(0.45)	(0.47)	(0.04)	(5.5)*	(5.3)*	(4.2)*

* n=39

When each soil variable were analyzed separately for *Striga* seed bank through regression analysis; pH, totN % and silt % showed significant results but not totC %, see Table 10. The explanation ratios for all soil variables were low in these analyses.

Table 10. Separately regression analyzes for each soil variables.

Predictor	*Striga* seed bank		
	R^2	Adj-R^2	p
pH	0.116	0.111	0.000
ohlsen-P (mg/kg)	0.002	0.000	0.542
totC %	0.003	0.000	0.447
totN %	0.036	0.031	0.006
Clay %	0.029	0.024	0.015
Sand %	0.002	0.000	0.477
Silt %	0.038	0.033	0.005

The regression analysis for all soil variables gave significant results for pH, total C% and total N%. Nitrogen was negatively correlated with the amount of *Striga* seed found in the soil. Silt% was removed from the analysis because of its correlation to another predictor. Only 204 cases out of 240 were used since 36 cases contained missing values and were therefore removed. The explanation ratio was higher, but still low with this analysis with a R^2 value at 0.331 (see Table 11). For residual plots see appendix 9.3.

Table 11. Regression analysis for *Striga* seed bank. R^2 = 0.331

Predictor	Coef	p
pH	0.45968	0.000
ohlsen-P (mg/kg)	-0.003283	0.180
totC %	0.7481	0.000
totN %	-13.066	0.000
Clay %	-0.00626	0.618
Sand%	-0.01547	0.142

Regression analysis (see Table 12) with only the significant variables pH, totC and totN gave significant results and similar Coef values as for the regression analysis with all variables present. However the explanation ratio was a bit lower with a R^2 value at 0.285 instead of 0.331 TotN had a negative Coef value.

Table 12. Regression analysis for *Striga* seed bank. R^2 = 0.285

Predictor	Coef	p
pH	0.38409	0.000
totC%	0.8049	0.000
totN%	-11.971	0.000

The C:N ratio from all soil samples varied from 9.2 to 16.8, see Figure 21. Bondo had the highest values with a C:N ratio from 10.2 to 16.8. In Siaya the C:N ratio varied between 10.8 and 14.9 and Vihiga had the lowest values: 9.2-11.8. A regression analysis of *Striga* seed bank and the C:N ratio gave a significant result, ($p < 0.000$) i.e. soils with a high C:N ratio also had a higher amount of *Striga* seed in the soil, however the R^2 was only 0.166. When combining the C:N ratio and the pH a regression analysis gave $R^2 = 0.224$ (Table 13).

Table 13. Regression analysis for *Striga* seed bank. R^2 = 0.224

Predictor	Coef	p
pH	0.31756	0.000
C:N ratio	0.12900	0.000

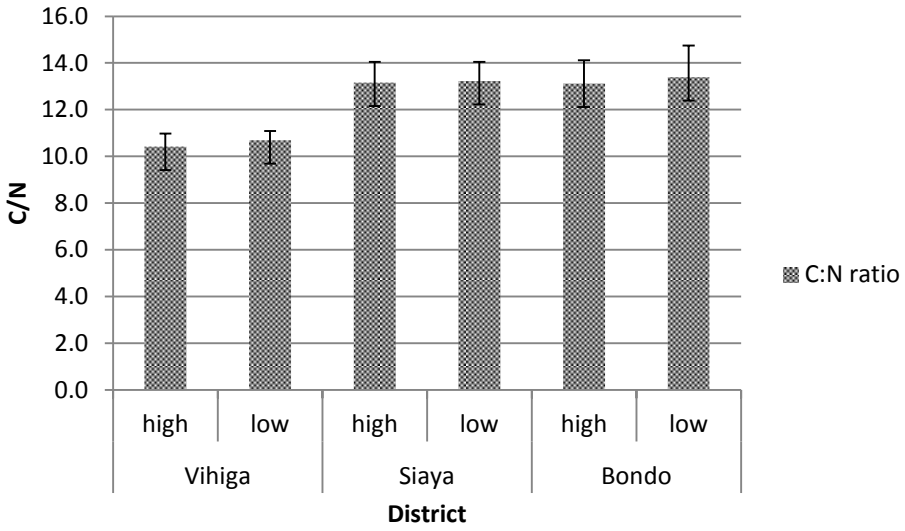


Figure 21. C:N ratio with stdev in the different districts.

For the *Striga* seed bank study there were in total missing data from 15 farms, giving a loss of 30 fields, since they were removed in pairs. In Katieno, Siaya 20 fields (i.e. 10 farms) contained missing values. In Vihiga there were not that many *Striga* seeds found in the soil samples, about one tenth of the amount found in Bondo. The variation of Striga seed found in the soil was higher in Bondo as well. In Siaya district high and low field differed and the variation for low field were the highest one, see Table 14 and Figure 22.

Table 14. Average *Striga* seed bank in sampled soil (stdev, no of fields).

District	Field status	*Striga* seed bank [no. of seeds]
Vihiga	High	2 (3, n=38)
	Low	3(4, n=38)
Siaya	High	6(9, n=29)
	Low	15 (35, n=28)
Bondo	High	21 (25, n=39)
	Low	22 (26, n=39)

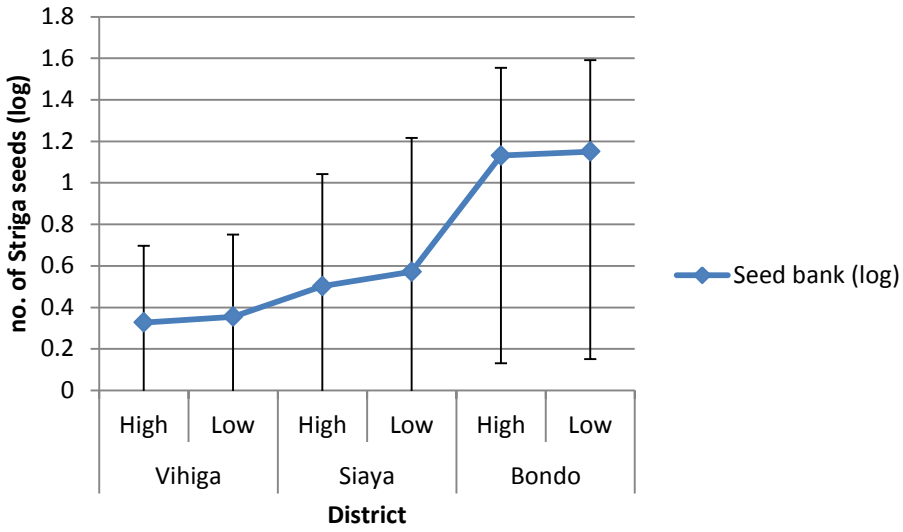


Figure 22. *Striga* seed bank (logged values) in the studied districts.

A fully nested analysis of variance design for *Striga* seed bank with district, sub-location, farm and field with farm indicated as a random factor gave significant results for district $P < 0.000$. This design did not however give any degrees of freedom in the error term (see Table 15) because of no replications at field level. As a result, the field level could not be tested.

Table 15. ANOVA table for fully nested GLM analysis for *Striga* Seed bank.

Source	DF	Seq SS	Adj SS	Adj MS	F	p
District	2	26.91294	26.40313	13.20156	55.50	0.000
Sub-location (District)	3	0.47526	0.47526	0.15842	0.67	0.575
Farm ID (District Sub-location)	99	23.54763	23.54763	0.23785	1.26	0.123
Field ID (District Sub-location Farm ID)	105	19.84164	19.84164	0.18897	**	
Error	0	*	*	*		
Total	209	70.77747				

Under the assumption that field was not nested under farm and that farm is a random factor the analysis of variance gave significant results for district as an explanation to *Striga* seed bank. The analysis gave: $P < 0.000$, $R^2 = 0.72$ and R-Sq (adj) = 0.4373. However, no significant effects of farm and field levels were obtained. The distribution of *Striga* seeds with the highest number in Bondo followed by Siaya and then Vihiga. Both the fully nested model and when field was not nested under farm gave the same results with only district being significant.

Clay and C:N ratio gave through correlation analysis significant values with a $p<0.041$ and a R of 0.132.

4.2.1 Farmer perception of Striga infestation and soil fertility

A regression analysis for farmer estimation of *Striga* infestation ratio on the field and the actual number of *Striga* seeds did not give a significant outcome. There was consequently no correlation between farmer estimation of *Striga* infestation (none, low, medium, high) and the

actual number of *Striga* seeds found in the soil sampled from the identified fields (data not presented).

Each soil variable was analyzed through variance analysis versus field, farm and district in a GLM design where farm was indicated to be a random factor. A fully nested design gave significant results for district and farm for pH, clay%, sand%, silt%, totC and totN. Ohlsen-P was only significant at district level. Due to zero degrees of freedom a fully nested design did not give any R^2 – values. Analyses at field level were not able to be performed in a fully nested design since there were no replicates. When field is assumed not to be nested within the farm only pH and totN were significant at field level, see Table 16. At field level only pH and totN% were significant.

Table 16. Analysis of variance for soil variables verses district, farm and field with field not nested under farm.

	pH	Ohlsen-P	Clay%	Sand%	Silt%	totC%	totN%
				[p]			
District	0.000	0.044	0.000	0.000	0.000	0.008	0.000
Farm	0.000	0.160	0.000	0.000	0.000	0.000	0.000
Field	0.056	0.621	0.736	0.699	0.918	0.054	0.007
R^2	0.6773	0.1038	0.7264	0.8296	0.7605	0.7645	0.7496

Total amount N found in the soil were significant for field status, where fields indicated as high had higher amount of N present (Figure 23).

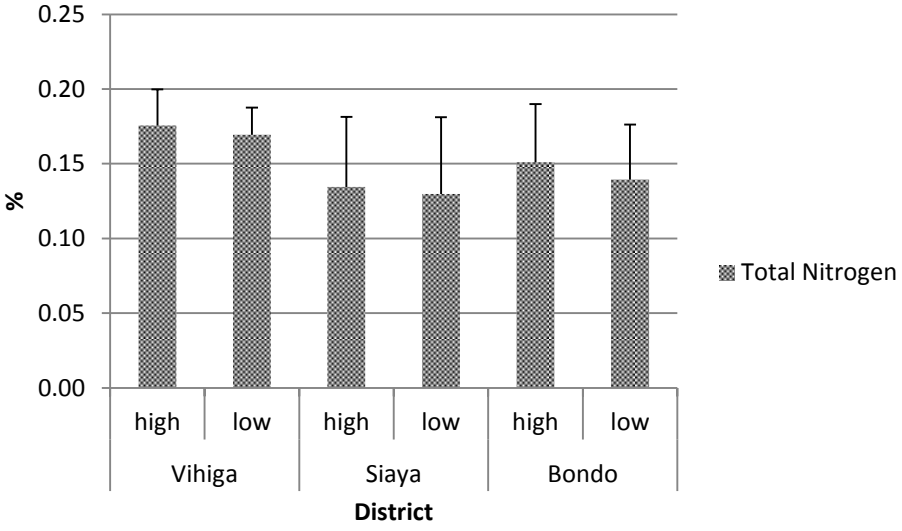


Figure 23. TotN% with stdev bars in the different districts.

4.3 Striga emergence in field

Data on *Striga* emergence (no of plants), maize plant density and maize yield were obtained from the field trial in Nyabeda, Siaya district and are presented in Table 17.

Table 17. *Striga* emergence trial in Nyabeda, Siaya district. Yield, *Striga* emergence and maize density in the installed plots on low respectively high soil fertility. DH04 (local maize), W303 (IR-maize) with and without fertilizer (F- and F+). (p<0.05)

Field Status	Treatment	Yield*	*Striga* emergence	Maize density
		[kg/ha]	[no. of plants/22.5m]	
High	DH04+F	3469 (1678)[a]	89 (143)[c]	152 (20)
	DH04-F	2280 (1414)[a]	124 (168)[c]	136 (21)
	W303+F	2890 (966)[b]	183 (201)[d]	176 (28)
	W303-F	2058 (1087)[b]	262 (385)[d]	166 (26)
Low	DH04+F	2380 (1640)[a]	474 (720)[e]	146 (25)
	DH04-F	1635 (1599)[a]	256 (371)[e]	132 (31)
	W303+F	1666 (768)[b]	1018 (785)[f]	178 (37)
	W303-F	1460 (795)[b]	955 (1102)[f]	167 (33)

*stdev; n=11.

A fully nested analysis of variance design with farm indicated as a random factor, gave significant results for variety both for yield and emergence. For emergence field status was also significant under the assumption that farm was a random factor and field was not nested within the farm. Analysis of variance gave significance for variety and farm as an explanation to both maize yield and *Striga* emergence. Field status was also significant for emergence. Whether the field was fertilized or not did not seem to be important for the emergence of *Striga* seeds or the maize yields, and no significant effects were obtained (Table 18 and Table 19). For residual plots see appendix 9.4.

Table 18. *Striga* emergence in both a fully nested and not fully nested analysis of variance.

	Fully nested $R^2 = 0.7245$			Not fully nested $R^2 = 0.4112$		
	DF	MS	p	DF	MS	p
FarmID	11	22.3642	0.718	11	2.0331	0.000
FieldID	12	34.7701	0.000	1	12.0580	0.000
Variety	1	4.2363	0.000	1	4.2363	0.004
Fertiliser	1	0.0032	0.905	1	0.0032	0.935
Var*Fert	1	0.0599	0.606	1	0.0599	0.724
Error	69	15.3687		80	0.4760	
Total	95	76.8024		95		

Table 19. Maize yield in both a fully nested and not fully nested analysis of variance.

	Fully nested $R^2 = 0.244$			Not fully nested $R^2 = 0.2095$		
	DF	MS	p	DF	MS	p
FarmID	11	4019590	0.128	11	4019590	0.012
FieldID	12	2029917	0.254	1	1007368	0.439
Variety	1	16570226	0.002	1	16570226	0.002
Fertilizer	1	2889971	0.182	1	2889971	0.192
Var*Fert	1	2265372	0.237	1	2265372	0.247
Error	69	109954445		80	1666326	
Total	95			95		

As mentioned both variety and field status were significant for *Striga* emergence. Cultivation of IR-maize (W303) lead to higher number of emerged *Striga* plants and fields indicated as low soil fertility had lower *Striga* emergence rate (Figure 24).

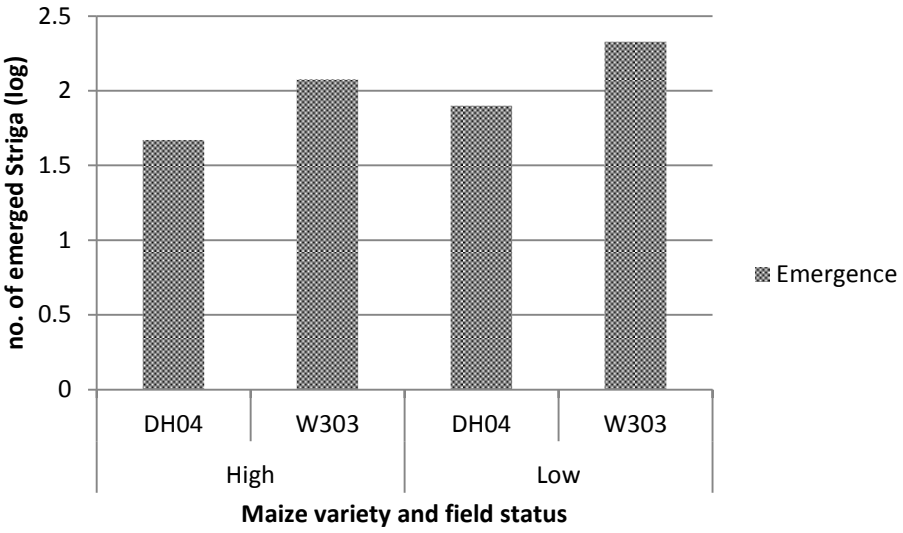


Figure 24. Maize variety and field status were significant for *Striga* emergence. DH04 was local maize and W303 was IR-maize.

Cultivation of local maize DH04 resulted in higher yield than the IR-maize W303 did regardless of fertilizer and field status (Figure 25).

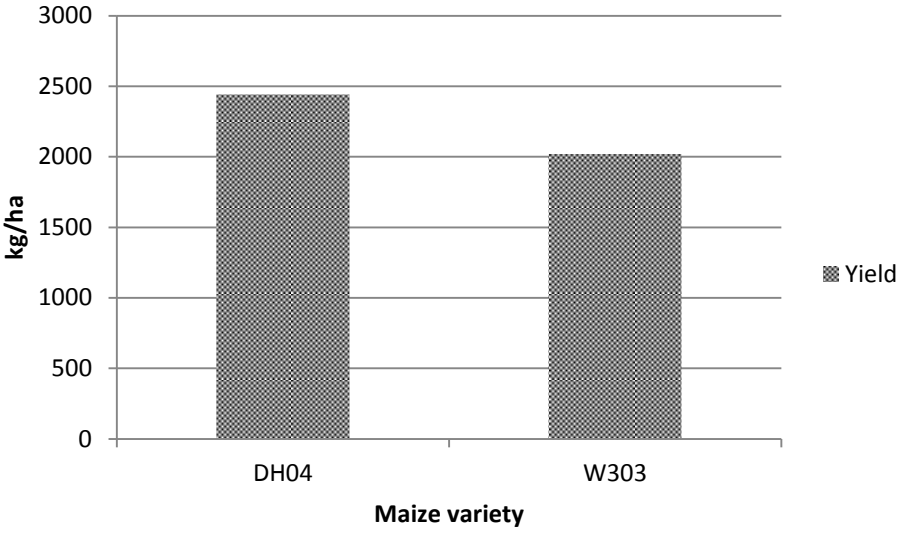


Figure 25. Maize variety was significant for maize yield. DH04 was local maize and W303 was IR-maize.

A fully nested analysis of variance, plant density gave significant results for farm, field, variety and fertilizer with an explanation ratio of 0.6052 (R^2) see Table 20. When not fully nested (field was not nested within farm) field was not significant and the R^2-value for that model was a bit lower with 0.518. IR-maize had significantly higher maize stand than local maize had this with an explanation ratio at $p < 0.000$

Table 20. ANOVA table with farm indicated as random factor. R^2 = 0.6052

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Farm ID	11	34068.6	34068.6	3097.1	7.33	0.000
Field ID	12	12809.6	12809.6	1067.5	2.53	0.008
Variety	1	21510.1	21510.1	21510.1	50.89	0.000
Fertilizer	1	4043.0	4043.0	4043.0	9.56	0.003
Fertilizer*Variety	1	106.3	106.3	106.3	0.25	0.618
Error	69	29165.9	29165.9	422.7		
Total	95	101703.5				

In Figure 26 one of the trials set up in Nyabeda, Siaya district can be seen. That field had according to the farmer low soil fertility and as can be seen in the photo the fertilized plots in the back were doing better.

Regression analysis for *Striga* emergence in the field trials and *Striga* seed bank from the soil in the field were not correlated, neither for local maize nor IR-maize in unfertilized fields. p = 0.082 and R^2=4.8%, see table 21.

Table 21. Regression analysis of *Striga* emergence and Striga seed bank in unfertilized plots. R^2= 0.048

	Coef	SE Coef	T	p
Constant	0.2983	0.1797	1.66	0.104
Striga emergence	0.14954	0.8383	1.78	0.082

Figure 26. Field trial in Nyabeda, Siaya district with local maize to the left and IR-maize to the right. In the back, fertilized and in the front, unfertilized. This field was considered to have a low fertility and that affect the crop growth more than the occurrence of *Striga* seemed to do. Photo: Miriam Larsson

4.4 Feedback to farmers

Not all farmers participating in the study showed up at the feedback meeting, however most were there. The farmers showed an awareness of the existing circumstances regarding soil fertility and *Striga* infestation. They also had an interest to know more about the soil fertility and *Striga* situation on their fields and how to manage the problem caused by *Striga* infestation. The general apprehension was that the farmers experienced *Striga* as a big problem but did not know themselves how to deal with it. The knowledge about *Striga* management practices varied between the districts, but was in general low.

5. DISCUSSION

5.1 Management history – interviews

Before constructing the questionnaires and conducting the interviews no model for analyzing the data were designed. No statistical analyses have therefore been performed on the data collected from the interviews. It is therefore difficult to say if there were any major factors regarding farmer management that had affected the present soil fertility status and the rate of *Striga* infestation on the different fields in the presented study.

While doing the interviews, difficulties in communication and comprehension were realized. The whole study was based on the interviews where two fields: one with low and one with high fertility were identified and later sampled from. It was then crucial that the enumerators helping in doing the survey were aware and educated on the issue on how to perform the task given. In this study the enumerators were chosen due to their mother tongue and knowledge of the tribe languages spoken in the areas. Not all of the enumerators had a general comprehension of English which made it difficult to assure that they understood what to do and why they were doing so when the training days and instructions were given in English. Only a few of the enumerators' had started some form of higher education and had knowledge of farming from a scientific point of view. This meant that the vast majority maybe did not know what to ask for, e.g. which field had the lowest and highest soil fertility respectively. It is presumable to believe that they asked for the best and worst field which for the farmer could mean the most and least productive field and then not in terms of high and low soil fertility. In the future, it could be a good idea to choose enumerators not only based on their language knowledge but on their agriculture knowledge and experience with scientific thinking and working. Then the understanding of the importance of performing the task exactly as given, e.g. sample the soil as instructed, would likely be greater. The enumerators were working in pairs and were responsible for one sub-location each which could have affected the outcome and the similarity between the answers obtained in each sub-location.

All 120 selected farmers were in-depth interviewed and answered the same questionnaire which consisted of 15 pages. An alternative way could have been to have a more general questionnaire with much fewer questions which all farmers in the district could have answered. Then a selected number representatively divided in all districts could have been interviewed in depth with an experienced person as an interpreter with several follow up visits this to ensure the creditability and accurateness of the answers given. The in-depth interview could then be the base for the investigation of farmer management impact on *Striga* infestation and soil fertility. In the future while doing this kind of studies to avoid misunderstandings between the scientist, enumerator and farmer the questionnaires can be translated into the local tribe language to further.

Either the household head or its spouse answered the questionnaire which most likely affected the answers given. Traditionally the work on the farm is distinctly divided between the male and the female with the woman doing most of the work (Shelton, 1996). The insight to how the farm was managed may be limited depending on who was performing the work and who was answering the questions.

All farmers participating in this study belonged to different farmer association groups. These groups experience of *Striga* control and management and involvement in farmers farming management varied between the districts. Some representatives from the farmer association groups were more educated and interested in the problems associated with *Striga*. Therefore the knowledge and help regarding *Striga* problems in those areas were more

present for the local farmers and could be an explanation to *Striga* prevalence, or the lack of it, in these areas.

5.1.1 Field identification

The whole study was based on the statement that the farmer correctly had chosen the two fields where he or she has the highest respectively lowest soil fertility and where he or she normally crops maize or other cereals. However, as mentioned before, it is presumable to believe that the farmer in fact chose the more productive field as their best field and the not so productive field as the worst field. Farmers' perception of soil fertility might not be in accordance to the scientifically classification of soil fertility, also the enumerators asking the question might not possess the right knowledge about the matter and therefore the ability to ask the question correctly.

Only one high and one low field were chosen from each farm giving no replicates at field level. The different farms could be viewed as the replicates, however if farmer management are supposed to be analyzed and discussed regarding to the fields, then the fields on the different farms within the district cannot be viewed as replicates. Alternatively several small plots could have been identified on the farms giving replicates to both high and low soil fertility. However most farms were small with few fields and since cereal cropping was a requirement it narrowed the number of available fields/plots further.

5.2 Soil fertility and Striga seed bank

District was the only factor that had a significant effect on *Striga* seed bank; showing the geographic differences. Field level could only be analyzed with the assumption that field was not nested within the farm, giving replicates at field level.

Striga seed bank was significantly correlated with the pH, total amount of C and N in the soil when performing the regression analysis. Through the single regression analysis, except pH, clay and silt content in the soil were also significant for *Striga* seed bank. Nitrogen was negatively correlated with the number of *Striga* seeds in the soil. Abunyewa (2003) stated the same correlation in his study in Ghana. pH was positively correlated with number of *Striga* found in the soil. pH in the districts varied between 5.6-6.3. The optimal pH for good soil fertility is about 6.0-6.8 (Eriksson et al., 2005). Bondo with the highest amount of *Striga* seeds had the highest pH range 6.2-6.3. This could imply that *Striga* prefers the same pH as considered to be optimal for having good soil fertility i.e. when most necessarily plant nutrients are available.

The results could in fact imply that *Striga* infestation and soil fertility status is correlated. The C:N ratio in Bondo was the highest followed by Siaya and Vihiga. The C:N ratio varied in all districts from 9.2 to 16.8. This can be compared to Sweden where on mineral soil the C:N ratio is about 10, this according to a study done by Eriksson et al. (2000). The study also showed that higher content of clay in the soil, the lower C:N ratio. This would imply that high clay content with a low C:N ratio would have less *Striga* seeds in the soil. However clay was positively correlated with *Striga* seed bank through the single regression analysis. Schultz et al. (2002) showed that *Striga* seed density was significantly lower when the C:N ratio was low compared to when it was high. The result in this study indicates the same with the highest C:N ratio in Bondo and also the highest *Striga* seed bank values there.

The amount of *Striga* seeds was, as stated, significantly higher in Bondo district than in the other districts. Samaké et al. (2005) stated that infestations of *Striga* are linked with the decline of soil fertility. Bondo with the highest *Striga* number had the lowest percentage of

external inputs to fields and also the highest C:N ratio. According to Ayongwa (2011), *Striga* control management will have no impact on cereal yield if soil fertility management is neglected. However there must be a threshold value when the soil is no longer regarded as poor and soil fertility management no longer are the primary focus for maintaining a high yield.

Studies of both Ayongwa (2011) and Vogt et al. (1991) demonstrated the importance and correlation between soil organic matter and *Striga* infestation. Increased amount of organic matter in the soil reduced the germination of *Striga* seeds. Organic matter is moreover an indicator of soil fertility (Eriksson et al., 2005) and can be used to test ditto. Soils with high quality organic matter have a low C:N ratio and the reduction of *Striga* seed survival are also greater. However in a study by Ayongwa (2011), it was shown that when the same amount of inorganic N was applied instead of organic matter *Striga*'s biomass reduced.

One of the main hypotheses was that *Striga* and soil fertility were correlated and fertile soils would have a lower *Striga* seed bank. According to Eriksson (2005) availability of plant nutrients is essential for good soil fertility. Fields with higher total amount of N, which is an indicator of good soil fertility, had lower *Striga* seed bank. However this factor was not enough to state whether the chosen fields actually had high and low soil fertility respectively.

Staff at Kibos center, where *Striga* seed bank counts were conducted, had recently been changed before the soil was sent there for analysis. That in combination with the many soil samples contained zero seeds raise the question about the creditability of the counting since the *Striga* numbers should not be that low in a *Striga* prone area. In this area *Striga* seeds are likely to be found in most soil samples and at a higher rate.

A major source of error for the soil analysis was how the soil was being sampled. The soil sampling was carried out at different weather conditions in the different locations which could have affected how the soil has been collected. A homogenous piece of soil from each spot in the field was supposed to be sampled, however that is not possible if the soil is dry. It is then likely to believe that more soil from the top layer is represented in the soil sample. It has also been indicated that not all enumerators collected the soil as demonstrated, i.e. in 10 spots equally divided on a W-shape in the field, or at the correct depth.

5.2.1 Farmer assumption of soil fertility status and Striga seed bank

The grading of results were not enough to conclude if the farmer knew if the soil fertility was good or poor in comparison to other farmers. The data available contained information on whether the farmer experienced that the soil fertility status was low, medium or high within the own farm. A study done by Karltun *et* al. (2011) in Ethiopia farmers had to rank the soil from 1-7 where 7 was the most fertile soil. If the farmers in this study had been asked to rank their soils instead of indicated the best respectively worst field it would probably have been easier to compare that result between the farms and also within the districts. A ranking of soil fertility status would also have facilitated a comparison between soil fertility status and the different soil variables studied.

Whether farmers were right in their assumption of which field had low, respectively high soil fertility, is hard to distinguish. However an analysis of variance gave significantly values for total amount of N. The fields indicated as high had higher amount of N which is an indication for good soil fertility (Eriksson, et al., 2005). Therefore it is presumable to assume that the farmers knew which one of their fields where high respectively low. The higher amount of N could e.g. be an explanation of higher fertilization ratio on these fields. However there is no reliable fertilization data for these fields to answer that.

Regression analysis of farmers assumption of the *Striga* infestation level and the actual *Striga* seed bank values showed that the farmer were not aware on which field they had none, little, medium or high *Striga* infestation.

5.3 Field trials – Striga emergence

Striga emergence in the field trials gave significant results for maize variety (local and IR-maize), farmer indication on high and low soil fertility and the farm itself. Since there was a significant difference between local maize and IR-maize it can be assumed that the use of IR-maize would better suppress the germination of *Striga* and lead to higher crop yields, because of IR-maize's mechanisms to kill *Striga* seedlings. However the results showed the opposite, i.e. highest yields were obtained with local maize and IR-maize resulted in the highest *Striga* emergence. The weather in western Kenya was unusually dry during this planting season and maize in general is sensitive for drought due to its shallow root system (De Barros, 2007). IR-maize is not as well adapted to the prevailing local climate as for local maize and that could be an explanation to why cultivation of IR-maize resulted in a lower yield. Due to these unfavorable weather conditions IR-maize might not developed as well as normal. The higher number of *Striga* emergence, both on low and high soil fertility field, could be explained by the fact that maize plant density in plots with IR-maize were significantly higher than the plant density for local maize.

The use of fertilizer did not affect the number of *Striga* plants emergence in the trials. This could imply that fertilizer is not the most important factor when it comes to reducing the amount of *Striga* emergence in the field. There were no significant correlation between *Striga* emergence in the trials and the number of *Striga* seed in the soil sampled from the fields. This is contrarily to what Kiwia (2009) found, that the amount of *Striga* seeds in the soil and the actual number of *Striga* emergence was strongly correlated. Field status was significant for *Striga* emergence. High fertility fields had a significantly lower emergence than low fertility fields had, supporting the statement that fields with high soil fertility would have lower *Striga* emergence. However the assessment of field status might not be the accurate.

According to Ayongwa (2011) farmers will get low yields even with low amounts of *Striga* present if soil fertility is not managed. To increase the yield only low doses of fertilizer is needed. Therefore Ayongwa (2011) believes that boosting the yield is better than controlling *Striga* itself. With low soil fertility and low *Striga* infestation which leads to low yield, the focus should according to Abundewa and Padi (2003) not necessarily be on *Striga* management, but on soil fertility improvement. Even though *Striga* number will increase with higher soil fertility, it is the main constraint and would be the priority (Abunewa and Padi, 2003). However Sjögren (2009) showed that the use of fertilizers decreased *Striga* populations with 42% over all seasons as the trials in his study went on. Ayongwa (2011) found that with a high rate of nitrogen application to the field a reduction of *Striga* infestation and biomass can be achieved. However fertilization had no significant impact on yield or *Striga* emergence in the trials. Only variety (local maize and IR-maize) was significant for explaining the yield. Both for local and IR-maize field indicated as high had less emergence of *Striga*. High soil fertility therefore seemed to be an important factor for *Striga* germination.

5.4 Feedback to farmers

The problems with *Striga* infestation and soil fertility cannot be managed without the farmers' willingness and interest to learn and change the way their farm are managed at present. Feedback showed that most farmers are genuinely interested in the matter and wanted to learn

more about how to control *Striga* infestation and how to improve or maintain good soil fertility. Most farmers practiced some form of control method even though the uses of modern technologies were relatively low. Due to limited resources the farmers want to be certain that the extra cost will be covered by a higher yield and that is also one of the reasons to why the farmers want to first gather more information about these technologies before they adopt them.

Most farmers do not find e.g. the use of crop rotation and none cropping of host crops as a good alternative method even though it not necessarily involves higher costs. These methods imply that another crop instead of maize would be planted. Since maize is the staple food it is the most attractive crop to plant. Even though the maize yield is low, the farmers experience a form of security to know that they at least have a small yield on their own farm. If they crop something else it means that they must be able to sell it to get money to buy maize instead. In spite of the fact that the problems linked to *Striga* would most likely reduce, soil fertility be improved, the yield be greater and the economic situation be better they do not dare to put it at stake.

6. CONCLUSION

Due to the diversity in farming systems in Africa, even within Kenya, implies that there is not a universally solution for *Striga* infestation. Soil fertility and *Striga* infestation is linked together, just attacking the *Striga* problem will not lead to higher yields. Therefore it is important to also improve the declining soil fertility or other major crop constraint factors experienced by the farmers to make farming sustainable. In Bondo many farmers indicated lack of water as the major crop constraint, then fertilization for an example would not have the greatest impact on the yield. It is important to change the farmers' view of cropping into a crop system which leads to improvement of the soil fertility. Most farmers participating in the study were interested and wanted to learn more about how to improve soil fertility, increase the yields and limit the damage caused by *Striga*. Even though the farmers were aware of the problems with declining soil fertility and *Striga* infestation they were not aware of the infestation rate *Striga* have infected the fields. This study cannot answer the question whether they are aware of the soil fertility status on their own fields either. It is important to tackle the problems linked with *Striga* and declining soil fertility. Both factors, if not managed, will lead to continuous crop losses. The question is whether resources should be focused on finding scientific evidence for linkage between *Striga* infestation, soil fertility and crop losses instead of just educating the farmers and providing them with e.g. clean sowing materials. However problems with *Striga* are most likely here to stay and without knowledge regarding the problems caused by it and the development of improved control methods it will be difficult to help the smallholder farmers.

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B. Vanlauwe 2011 E-mail.

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9. APPENDIX

9.1 Method descriptions

9.1.1 pH and ohlsen-P through wet chemistry

Document Ref.: SPLAB/SOP/3.1

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Revision : 00
Author : LS
Date Issued : 11/05/2011

TSBF Soil and Plant Laboratory Procedure on determination of Soil pH in Water

1. Background

This standard method uses a soil:water ratio of 1:2.5.

2. Equipment

2.1. pH meter
2.2. Multiple dispenser, 25 mL
2.3. Reciprocal shaking machine

3. Supplies

3.1. Combination electrode for pH meter
3.2. Calibrated spoon, 10 mL (Custom Laboratory Equipment)
3.3. Plastic bottles, 60 mL Nalgene or Azlon

4. Consumables

4.1. pH 4 buffer

4.2. pH 7 buffer

NOTE: The pH of buffer solutions should at the lower and higher end of the expected pH values of soil samples.

5. Procedure

5.1. Extraction

Analyses are conducted in batches of 33 with 30 soil samples, 2 repeated samples and 1 standard soil sample.

5.1.1. Scoop 10 mL of soil and pour into a 60 mL bottle.

5.1.2. Add 25 mL distilled water to bottle with dispenser.

5.1.3. Shake for 10 minutes on the reciprocal shaker at medium speed.

5.1.4. Let stand for 20 minutes.

5.1.5. Stir again for 2 minutes.

5.2. Calibration of the pH meter

5.2.1. Rinse the electrode with de-ionised water to remove accumulated dust. Blot the drops of water using tissue paper. Do not wipe the electrode tip with the tissue, as this can create static charge and cause unstable readings.

5.2.2. Program the ph meter to the calibration mode and immerse the electrode into pH 7 buffer.

5.2.3. After the reading stabilizes (about 1 minute), accept the ph of 7 using the calibration button.

5.2.4. Remove electrode, rinse with distilled water, and blot off the remaining drop of water with tissue paper. Immerse the electrode into pH 4 buffer. After 1 minute, adjust to ph 4.00 using the calibration button.

5.2.5. Repeat the calibration until the values obtained for pH buffers agree within ± 0.02 pH unit of the theoretical values.

5.3. Determination of soil pH

5.3.1. Immediately before pH measurement of each sample, stir the sample 5 seconds with a glass or plastic stirring rod. Allow the soil to settle 30 seconds before proceeding. Do not continue stirring during pH measurement.

5.3.2. Immerse electrode into 60 mL bottle with soil. Always immerse the electrode to the same depth in the bottles, because repeatability of readings depends upon the procedure being exactly the same each time. Take care not to strike the bottom of the sample bottle with the electrode tip.

5.3.3. Record pH reading after reading stabilizes. About 30 seconds to 1 minute is usually sufficient. If pH reading is very slow to stabilize, it is probably due to malfunction of the combination electrode. Follow manufacturer's instruction for maintenance of electrodes before proceeding.

5.3.4. Remove electrode from bottle, rinse with distilled water, and continue with samples. After each 11 samples, re-check one of the buffer solutions to ensure instrument and electrode stability. After each tray of 33 samples, check and record pH values for both buffer solutions. If values are more than ± 0.02 from theoretical, reset the correct values before continuing with samples.

6. Quality Control

6.1.1. Two standard samples- Katumani soil and Embu soil are used to verify the repeatability of analysis. The results should be entered into the standards sheet and should be within 10% of the median value.

6.1.2. Sample repeats are carried out within each batch of 42 samples. The variation within the repeats should be less than 5%. If greater, the analysis must be repeated as it indicates that the results are not repeatable.

7. Equipment Maintenance

The ph meter should be wiped with a damp cloth after use. The electrode should be stored in a vial of buffer ph 7. The electrode should be checked before use to ensure it has not dried out. If it has dried out, it should be replaced.

8. Disposal practices

The soil samples should be disposed in the soil bucket for eventual disposal into the soil pit. The plastics and glassware should be allowed to stand in tap water before being washed using the lab procedure for cleaning of glassware document reference SPLAB/QP/5.1/01

TSBF Soil and Plant Laboratory Procedure on analysis of extractable inorganic phosphorus and exchangeable potassium in soils using modified olsen extractant

1. Background

Many extraction techniques for plant-available phosphate have been developed. The modified Olsen extractant is convenient for routine use because inorganic P, exchangeable K and micronutrients can be determined from the same extract.
NOTE: "Modified Olsen" refers to a number of modifications of the original Olsen extract, each somewhat different. Direct comparisons of data derived from different modifications may not be possible.

2. Equipment

2.1. Balance, 0.01 g readability

2.2. Diluter-dispenser with 15 and 10 mL syringes (Custom Laboratory Equipment)

2.3. Multiple dispenser, 25 mL

2.4. Reciprocal shaker

2.5. UV Spectrophotometer with flow cell

2.6. Flame photometer

3. Supplies

3.1. Eppendorf Multipette pipettor and combitips, 12.5 mL

3.2. Calibrated spoon, 2.5 mL (Custom Laboratory Equipment)

3.3. Plastic Nalgene bottles, 60 ml

3.4. Polyethylene carboy, 20 L, graduated

3.5. Test tube rack

3.6. 1-litre measuring cylinder

3.7. Volumetric flasks (2000 mL, 1000 mL, 500 mL, 250 mL, 100 mL)

3.8. Volumetric pipettes (25 mL, 20 mL, 15 mL, 10 mL, 5 mL)

3.9. Pyrex beaker, 1 L

4. Consumables

Whatman No. 5 filter paper, 12.5 cm diameter

5. Chemicals

All chemicals used are analytical reagent grade.

5.1. Potassium dihydrogen phosphate (KH_2PO_4)

5.2. Potassium chloride (KCl)

5.3. Sodium hydrogen carbonate (sodium bicarbonate, $NaHCO_3$) –

5.4. Disodium EDTA (Ethylene diamine tetra-acetic acid disodium salt

5.5. Ascorbic acid

5.6. Ammonium molybdate

5.7. Antimony potassium tartrate

5.8. Sodium hydroxide (NaOH) pellets

5.9. Concentrated sulphuric acid (H_2SO_4, about 18 M)

5.10. Superfloc 127, a non-ionic flocculating agent

6. Reagents

6.1. Superfloc solution, 5 g/L: In a large beaker, stir about 700 mL of deionised water rapidly enough to create a gentle vortex. Slowly sift 5 g of Superfloc 127 into the edge of the vortex. Stir for 1 to 2 hours until dissolved, then dilute to 1 litre in a measuring cylinder. Store in a bottle.

Note: Do not exceed about 400 RPM stirring speed, as excessively vigorous stirring will break up the long molecules of the flocculant.

6.2. Soil extracting solution (0.5 M $NaHCO_3$ + 0.01 M EDTA, pH 8.5): Dissolve 840 g $NaHCO_3$ in about 10 L deionized water in a 20 litre carboy. Dissolve in a separate container 74.4 g disodium EDTA and add to the carboy. Add 200 mL of Superfloc solution and make up to

nearly 20 L with deionized water. Add 20% NaOH solution while stirring and adjust the pH of the extractant to 8.5. About 90 mL of 20% NaOH solution are required to raise the pH to 8.5. When testing the ph, Do not put the pH electrode in the extractant carboy, but remove a subsample of extractant to test the pH. Discard the subsample -- Do not return it to the carboy. (The pH electrode contains concentrated KCl solution, which diffuses into the test solution, and thus would contaminate the extractant with potassium).

Mix and make up to 20 L with deionized water.

6.3. NaOH, 20% (about 5 M): Dissolve 200 g NaOH pellets in about 800 mL deionized water, cool and then dilute to 1 litre with deionized water.

6.4. Phosphorus colour reagent, concentrated: Add 1 g of antimony potassium tartrate to about 400 mL deionized water in a 1000 mL volumetric flask. Add slowly, with mixing, 165 mL conc. H_2SO_4 to the flask, and allow to cool. In a separate container, dissolve 7.5 g ammonium molybdate in about 300 mL deionized water. Add to the cooled acid antimony solution in the 1000 mL volumetric flask, and make to volume with deionized water. Store refrigerated in a brown bottle.

6.5. Working phosphorus colour reagent, prepared fresh daily as needed: Add 150 mL of concentrated P colour reagent to a 1000 mL volumetric flask, and make to volume with deionized water. Add and dissolve 1 g of ascorbic acid.

NOTE: This colour reagent differs from the P colour reagent used with other P determinations, in that the final concentrations of chemicals in this P analysis are less than those in the other methods. We have found that the higher concentrations of molybdate reagent cause precipitation of the coloured phosphomolybdate complex at higher P concentrations. This precipitation is apparently caused by the EDTA contained in the soil extracting solution. The colour reagent described here avoids the precipitation problem up to about 0.5 mg P/L final concentration.

7. Standards

7.1. Potassium

7.1.1. Stock potassium solution (500 mg K/L): Dry about 10 g KCl at 105°C for 2 hours. Cool and store in a desiccator. Dissolve 0.9533 g of the dried KCl in deionized water, and make to 1000 mL in a volumetric flask. Store in a refrigerator.

7.1.2. Working standards in $NaHCO_3$ extracting solution (0, 10, 20, 30, 40, and 50 mg K/L): Pipette 0, 5, 10, 15, 20, and 25 mL of the 500 mg K/L intermediate stock solution into labelled 250 mL volumetric flasks, and make to volume with the $NaHCO_3$ extracting solution. Store in plastic bottles in a refrigerator.

NOTE: During actual determination of K, the flame photometer can be set to read results directly in me K/100 mL soil. Assuming 2.5 mL soil and 25 mL of extractant, the concentrations of the above standards can be set to 0, 0.26, 0.51, 0.77, 1.02, and 1.28 me K/100 mL soil.

7.2. Phosphorus

7.2.1. Stock phosphate solution (500 mg P/L): Dry about 7 g KH_2PO_4 at 105°C for 2 hours. Cool in a desiccator. Dissolve 1.0986 g of the dried KH_2PO_4 in deionized water and make up to 500 mL in a volumetric flask.

7.2.2. Intermediate stock phosphate solution (50 mg P/L): Pipette 25 mL of 500 mg P/L solution into a 250 mL volumetric flask and make to volume with deionized water.

7.2.3. Working standards in $NaHCO_3$ extracting solution (0, 1, 2, 4, and 5 mg P/L): Using an Eppendorf Multipette, pipette 0, 1, 2, 4, and 5 mL of the 50 mg P/L solution into labelled 50 mL volumetric flasks. Make to volume with the $NaHCO_3$ extracting solution and mix well.

8. Procedure

8.1. Extraction

8.1.1. Analyses are conducted in batches of 33 (one tray of samples) with 30 soil samples, 2 blanks, and 1 standard soil. Four trays are conveniently done in one group. Of the 120 soil samples, 10 to 20 percent should be repeat samples.

8.1.2. Tare 2.5 mL spoon with holder on balance.

8.1.3. Scoop 2.5 mL of soil.

8.1.4. Weigh spoon with soil and holder. Record weight.

8.1.5. Carefully pour the soil into a 60 mL bottle, add 25 mL extracting solution to bottles

8.1.6. Shake for 10 minutes on the reciprocal shaker.

8.1.7. Filter the suspension by gravity through Whatman No. 5 filter paper into clean 60 mL bottles.

8.2. Flame photometric determination of K

It is important that the aliquot for K determination be taken first, as the colour reagent for P determination contains K, which could contaminate the extract and cause erroneous results.

8.2.1. Transfer 2 mL of sample or standard and 8 mL of water to clean 60 mL bottles, and swirl gently to mix. NOTE: According to the K status of a given soil, this dilution may need to be altered to obtain readings within the linear range of the flame photometer (up to 10 mg K/L).

8.2.2. Set up flame photometer:

8.2.2.1. Check that there is fresh desiccant in the drying bottle which is installed in the air supply line.

8.2.2.2. Make sure the constant-head drain U-tube is full of water, with no air bubbles, and that the drain cup is fully seated down in the spring-clip holder.

8.2.2.3. Turn on the fuel supply at source. The fuel adjustment on the photometer should be open 9 to 10 turns, but not more than 13 turns. This setting is for normal cooking gas; if using another fuel source, refer to instrument manual for proper setting.

NOTE: If it is necessary to close the fuel supply valve on the instrument, close it very gently. DO NOT tighten further after the knob is closed, or the delicate valve will be damaged.

8.2.2.4. Open the viewing port for inspection of the flame conditions. This port should be open only during ignition and warm-up; it must be closed during actual analysis of samples.

8.2.2.5. Depress the "power" switch. The "power on" light will be illuminated, the air compressor will start and an ignition cycle will commence. If the flame does not light, wait 60 seconds, open the fuel adjustment one turn more, and depress the power switch again. DO NOT open more than 4 turns more than the standard setting of 9 turns.

8.2.2.6. Set the filter selector to the required ("K") position.

8.2.2.7. Insert the nebulizer inlet tube in a beaker containing approximately 100 mL of diluent and allow 15 minutes for operating temperature to stabilize. This ensures a stable burner temperature when solutions are aspirated after the warm up period.

8.2.2.8. While aspirating the zero standard, adjust the "blank" control so that the display reads zero.

8.2.2.9. Aspirate the highest concentration standard.

8.2.2.10. Allow 20 seconds for a stable reading and then adjust "coarse" and "fine" controls for a convenient reading. With the above standard concentrations and soil:extractant ratio, the highest K standard can be set to read directly in me

K/100 mL soil. This setting should be 1.28 me K/100 mL. The standard series should then read 0, 0.26, 0.51, 0.77, 1.02 and 1.28 me K/100 mL soil.

8.2.2.11. Carefully adjust the "fuel" control for a maximum reading on the display ensuring that only small adjustments are made, with a pause of several seconds between adjustments.

8.2.2.12. Remove the standard solution, wait 10 seconds, then aspirate the zero standard solution for 20 seconds. Adjust the "blank" control for a 0.0 reading. Remove the blank solution and wait 10 seconds.

8.2.2.13. Repeat steps h, i, and j until the blank reading is 0.0 (within ± 0.02) and the calibration reading is within ± 2%.

8.2.2.14. Aspirate each of the remaining calibration standards for 20 seconds (starting with the lowest concentration to avoid carryover), again allowing 10 seconds between measurements.

8.2.2.15. Aspirate each of the diluted unknowns for 20 seconds, then note the readings.

8.2.2.16. After each tray of 33 samples, re-check one or two standards to ensure instrument stability. If the highest standard is more than ± 0.03 different from the actual value of 1.28, reset the instrument and repeat sample readings. After reading all samples, re-read standards and record the readings.

8.2.2.17. If a sample gives a higher concentration than the highest standard, it must be further diluted using the bicarbonate extractant and reanalysed. The value obtained should be multiplied by the dilution factor to give the correct concentration.

8.3. Colorimetric determination of P

8.3.1. Dispense 2 mL of standard solution or filtered extract, 8 mL of deionized water and 10 mL of working P colour reagent into a clean 60 mL bottle using Custom Labs diluter-dispenser.

8.3.2. Leave for 1 hour for colour to develop fully. The colour is stable for only a short while; the coloured molybdate-P complex tends to precipitate, especially for higher concentrations of P.

8.3.3. Immediately after full colour development, read the standard and sample absorbance/concentration at 880 nm. The spectrophotometer should be turned on at least 30 minutes before running samples and standards. Determine absorbance values for the standards to check linearity of the standard curve and proper functioning of the spectrophotometer. Then calibrate the

spectrophotometer in concentration mode, setting the calibration with the 4 mg P/L standard. Read blanks and samples in concentration mode.

8.3.4. If a sample gives a higher concentration than the highest standard, it must be further diluted using the bicarbonate extractant and reanalysed. The value obtained should be multiplied by the dilution factor to give the correct concentration.

9. Calculations

9.1. Exchangeable K

The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

9.1.1. Exchangeable K (soil volume basis):

EXK100M = EXKCONC - EXKBLNK

EXK100M = exchangeable K (me/100 mL soil)
EXKCONC = Concentration of K in sample (instrument reading for sample, in me/100 mL soil)
EXKBLNK = Concentration of K in blank (instrument reading for blank, in me/100 mL soil)

9.1.2. Exchangeable K (soil mass basis):

$$EXK100G = EXK100M \left(\frac{EXKSOLVL}{EXKSOLWT}\right)$$

EXK100G = exchangeable K (me/100 g soil)
EXKSOLVL = Volume of extracted soil (mL)

9.2. Exchangeable Phosphorus

The mean blank value must be subtracted from sample values to give a corrected concentration for the samples.

Phosphorus concentration in soil (EXPMGKG) (mg P/kg):

$$\frac{(EXPCONC - EXPBLNK)\ (EXPVOL)}{EXKSOLWT}$$

EXPCONC = Phosphorus concentration for sample (mg P/L)

EXPBLNK = Phosphorus concentration for blank (mg P/L)
EXPVOL = Volume of extracting solution (mL)
EXKSOLWT = Weight of dry soil extracted (g)

9. Quality Control

9.1.1. Two standard samples- Katumani soil and Chuka soil are used to verify the repeatability of analysis. The results should be entered into the standards sheet and should be within 10% of the median value.

9.1.2. Sample repeats are carried out within each batch of 33 samples. The variation within the repeats should be less than 5%. If greater, the analysis must be repeated as it indicates that the results are not repeatable. The variataion is calculated as

Variation %= $\frac{\text{Stdev}}{\text{Average}} * 100$

9.1.3. The repeatability of standard readings on the UV spectrometer should be analysed to ensure the drift is not > 3 %. This indicates the stability of the readings.

10. Disposal practices

The soil samples should be disposed in the soil bucket for eventual disposal into the soil pit. The plastics and glassware should be allowed to stand in tap water before being washed using the lab procedure for cleaning of glassware document reference SPLAB/QP/5.1/01

9.1.2 IR-analysis of C and N

NIR

"In brief" Air dried and 2mm sieved soil samples were scanned on Bruker Multi Purpose Analyzer (MPA) FT IR Spectrometer using Diffuse reflectance mode, an FT IR spectrum was obtained at a waveband between 12500 to 4000 cm-1(wavenumbers)"

CN

"The CN samples were analyzed by the dry combustion method using the Thermo scientific Flash EA1112. 20 mg of dried soil samples were weighed in tin capsules and combusted at 950 C. The resultant elemental gases were quantified relative to change in thermal conductivity to give percent C and N."

9.1.3 Soil particle size analyses by hydrometer method

Background

The particle size analysis of soil estimates the percentage of sand, silt and clay particles comprising the soil. 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 vertical velocities of the particles through a water column, i.e. the sedimentation rate. Sedimentation rate is dependent upon liquid temperature, viscosity, and the diameter and specific gravity of the falling soil particles.

Soil is dispersed into individual particles after pretreatment with hydrogen peroxide to destroy organic matter, and addition of sodium hexametaphosphate to aid dispersion, then dispersed throughout a water column and allowed to settle. Hydrometer measurements quantify the amount of material remaining in suspension at specific time intervals, which in turn can be related to the amounts of sand, silt and clay in the soil.

Equipment

1. High speed stirrer with cup receptacle ("milk-shake mixer")
2. Balance, 0.01 g readability
3. Mechanical shaker (if stirrer is not available)
4. Hot water bath

Supplies

1. Bouyoucos hydrometer, graduated in g/L
2. Measuring cylinders, 1000 mL, one per soil sample
3. Plastic beakers, 400 mL, one per soil sample
4. Wash bottle
5. Thermometer, 0 to 110°C
6. Watch glasses to fit 400 mL beakers
7. Stop watch
8. Glass or plastic stirring rods fitted with rubber tips, one per soil sample
9. Rubber stoppers to fit measuring cylinders, or plunger and rod to fit cylinders, for mixing soil suspensions.
10. Volumetric flasks, 1000 mL
11. Stopwatch, or clock with sweep second hand

Chemicals

1. Hydrogen peroxide, 30% solution, GPR grade
2. Amyl alcohol
3. Sodium hexametaphosphate, technical grade

Reagents

1. Sodium hexametaphosphate, 10% solution: Dissolve 100 g of sodium hexametaphosphate in 1 litre of distilled water. This solution should not be stored over one month.

Procedure

1. Weigh 50 ± 0.5 g of air-dry soil, sieved to pass a 2 mm sieve, into a 400 mL beaker. If soil is very sandy, use 100 g of soil. In each day's analysis, include one standard soil sample and one blank.

2. Add 125 mL of distilled water and stir the mixture to wet the soil thoroughly.

3. Place beakers with soil into a hot water bath at 85 to 90°C.

4. Add 5 mL 30% hydrogen peroxide and stir gently with a stirring rod. If necessary, add 1 or more drops of amyl alcohol to minimize foaming. Cover with a watch glass. Add further 5-mL portions of hydrogen peroxide until reaction (frothing) ceases, indicating complete destruction of organic matter. Unless soil is high in organic matter, about 20 mL total of hydrogen peroxide is usually sufficient.

5. Heat the beakers for a short while longer, until no more bubbles appear.

NOTE: Ensure that the hydrogen peroxide is fully destroyed, as bubbles from residual hydrogen peroxide will cause erroneous hydrometer readings.

6. Remove the beakers from the water bath and allow to cool.

7. Add 10 mL of 10% sodium hexametaphosphate solution to each sample. Allow to stand for 10 minutes.

8. Transfer the sample to the mixer cup, and mix for two minutes with the high-speed stirrer. NOTE: If high-speed stirrer is not available, transfer samples to leakproof bottles and shake overnight on a flat-bed or end-over-end shaker.

9. Quantitatively transfer the suspension into a 1000 mL measuring cylinder, using distilled water to wash all soil particles into the cylinder. Fill to the 1000 mL mark with distilled water.

10. Prepare a blank cylinder containing 10 mL of 10% sodium hexametaphosphate solution, and fill to 1000 mL with distilled water.

11. Thoroughly mix the cylinders by fitting with a rubber bung and inverting the cylinder 10 times. Alternatively, the cylinders may be mixed with a circular plunger attached to a metal or wooden rod. Start the stopwatch immediately when mixing is complete.

12. After mixing, quickly add 2 to 3 drops of amyl alcohol to the cylinder, and after 20 seconds place the hydrometer gently into the suspension.

13. At 40 seconds, take a hydrometer reading and measure the temperature of the suspension. Also take a hydrometer reading in the blank cylinder.

14. Allow the cylinders to stand undisturbed for two hours. Avoid locations which are windy or in direct sun.

15. After two hours, take hydrometer and temperature readings in both sample and blank cylinders.

Calculations

1. Corrected hydrometer readings

a) Corrected hydrometer reading at 40 seconds (PSH40COR):

$$(PSH40SAM - PSH40BLK) + [(PST40 - 20)\ 0.36]$$

b) Corrected hydrometer reading at 2 hours (PSH2HCOR):

$$(PSH2HSAM - PSH2HBLK) + [(PST2H - 20)\ 0.36]$$

where PSH40SAM = Hydrometer reading at 40 seconds for sample
PSH40BLK = Hydrometer reading at 40 seconds for blank
PST40 = Temperature at 40 seconds
PSH2HSAM = Hydrometer reading at 2 hours for sample
PSH2HBLK = Hydrometer reading at 2 hours for blank
PST2H = Temperature at 2 hours

2. Percent clay (CLAY)

$$\frac{(PSH2HCOR)\ 100}{PSSLWT}$$

where PSSLWT = Weight of air dry soil (g)

3. Percent sand (SAND)

$$100 - \frac{(PSH40COR)\ 100}{PSSLWT}$$

4. Percent silt (SILT)

100 - SAND – CLAY

9.1.4 Elutriation method for Striga hermonthica seed bank analysis at Kibos center

This system was designed for use with *S. asiatica* by Dr. R.E. Eplee of the Whiteville Methods Lab, Whiteville, NC, USA and has been described elsewhere in detail (Eplee and Norris, 1990). Basically the system consists of an underflow elutriator and a separation column (Plate 3.1). The elutriator is designed to separate seeds from soil by vigorous agitation and a quiescent up-flow of water. Sieves are placed at the mouth of the elutriator

sequentially with the 20 mesh on top, the 70 mesh in the middle and the 170 mesh, where the seeds collect, at the bottom. A sample of 500 g soil prepared as described earlier was introduced into the elutriator which was filling with water. The soil-water mixture was agitated with the elutriator using a low flow rate for 10 minutes followed by 2 minutes with a high flow rate.

After elutriation the residual fraction on the 170 m sieve was transferred into the separation columns which were already half filled with a solution of potassium carbonate (K_2C0_3) with a specific gravity of 1.4 gm ml^{-1}. The separation columns, which are 1 m in length with a 10 cm diameter, allowed for the separation of both particles lighter than *S. hermonhica* seeds and any soil particles denser than the seed. After washing this fraction into the glass columns, water was slowly added to the column to prevent mixing. The columns were allowed to stand for 20 minutes without agitation. *S. hermonhica* seeds aggregated at the interface of the water and the potassium carbonate solution. Materials lighter than *S. hermonhica* were removed from the top of the water using suction while those heavier than *S. hermonhica* were drained off from the bottom of the column. The interface materials were collected onto nylon screens made of monofilament cloth and placed under a microscope for identification and seed counting. The system had earlier been tested and calibrated with three soils which represent the majority of the soils in the *S. hermonhica* infested areas of western Kenya (**Vertisol** and **Planosol** collected from Kibos and a **Ferralsol** collected near Alupe) The rate of recovery averaged 85% and was fairly consistent (Table 3.4). This is compared to a recovery rate of between 90-100% obtained by Visser & Wentzel, (1980) and Hartman & Tanimonure, (1991).

Table. 3.4. Percent recovery of *S. hermonhica* seeds introduced into uninfested soil sample.

Replication	Soil Type		
	Kibos	Alupe	Miwani
	---------- % recovery ----------		
1	81	78	84
2	88	89	76
3	86	93	82
Mean	85	87	81

Source: From Ndung'u *et. al*., 1993.

9.2 Number of years with Striga on the farm

Farm no.	Munoywa	Bukulunya	Katieno	Nyabeda	Abom	Ajigo
1	12	20	3	10	20	10
2	10	60	10	2	10	3
3	3	4	3	3.5	10	10
4	20	10	2	30	1	2
5	20	3	39	4	3	3
6	3	10	2	5	0	5
7	20	30	20	20	4	5
8	60	10	2	4	6	1.5
9	20	50	9	8	4	10
10	15	20	3	30	0	2
11	10	10	10	10	3	20
12	3	4	3	5	2	2
13	2	5	10	4	4	25
14	20	15	10	20	4	3
15	0	20	3	10	4	10
16	6	20	2	5	1	20
17	10	10	29	50	10	10
18	20	10	3	10	3	10
19	10	5	22	20	2	10
20	5	3	4	30	2	2

9.3 Soil analyses

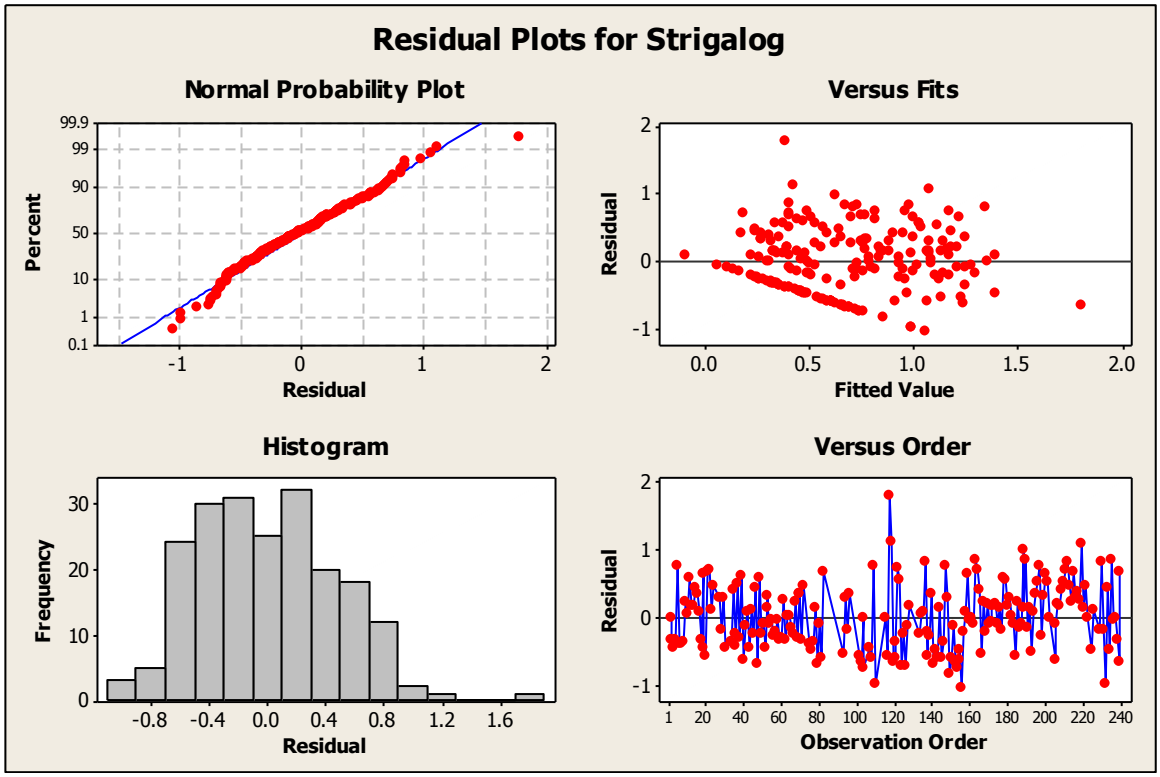


Figure 27. regression analysis with *Striga* log as predictor for pH, ohlsen-P, C, N, clay, sand and silt.

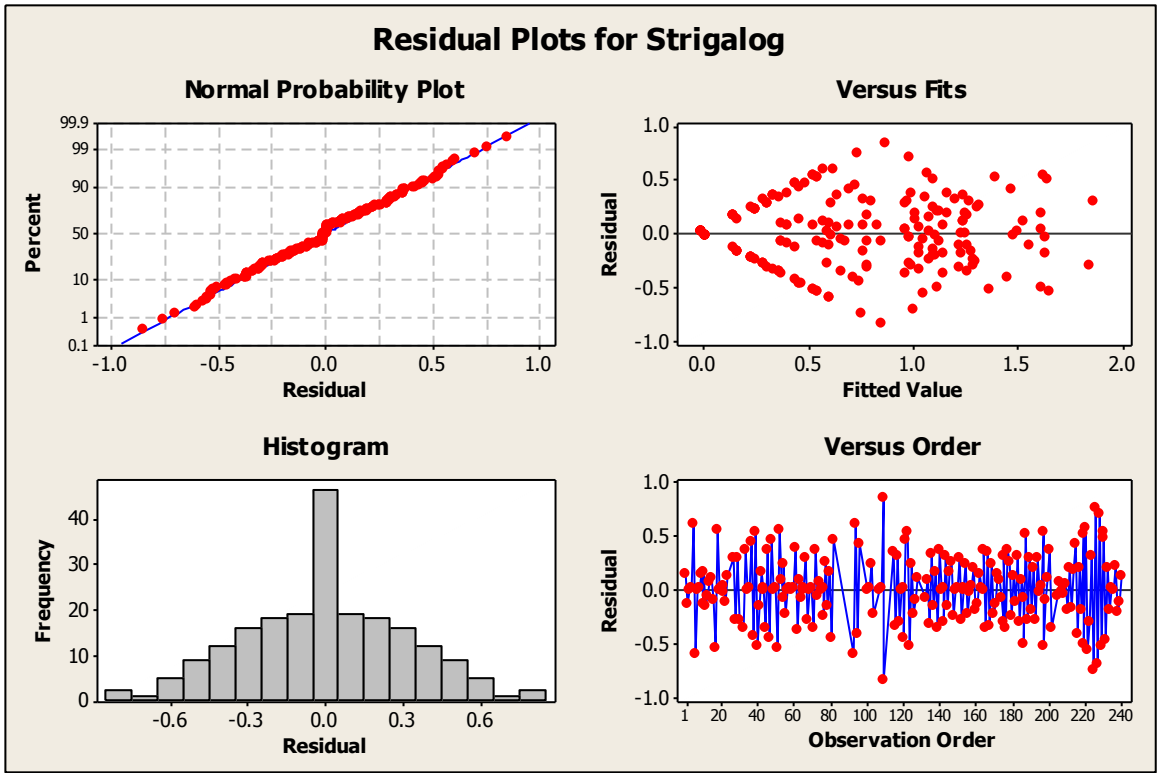


Figure 28. GLM for *Striga* seedbank. Farm as random factor. Field not nested within farm, sub-location and district.

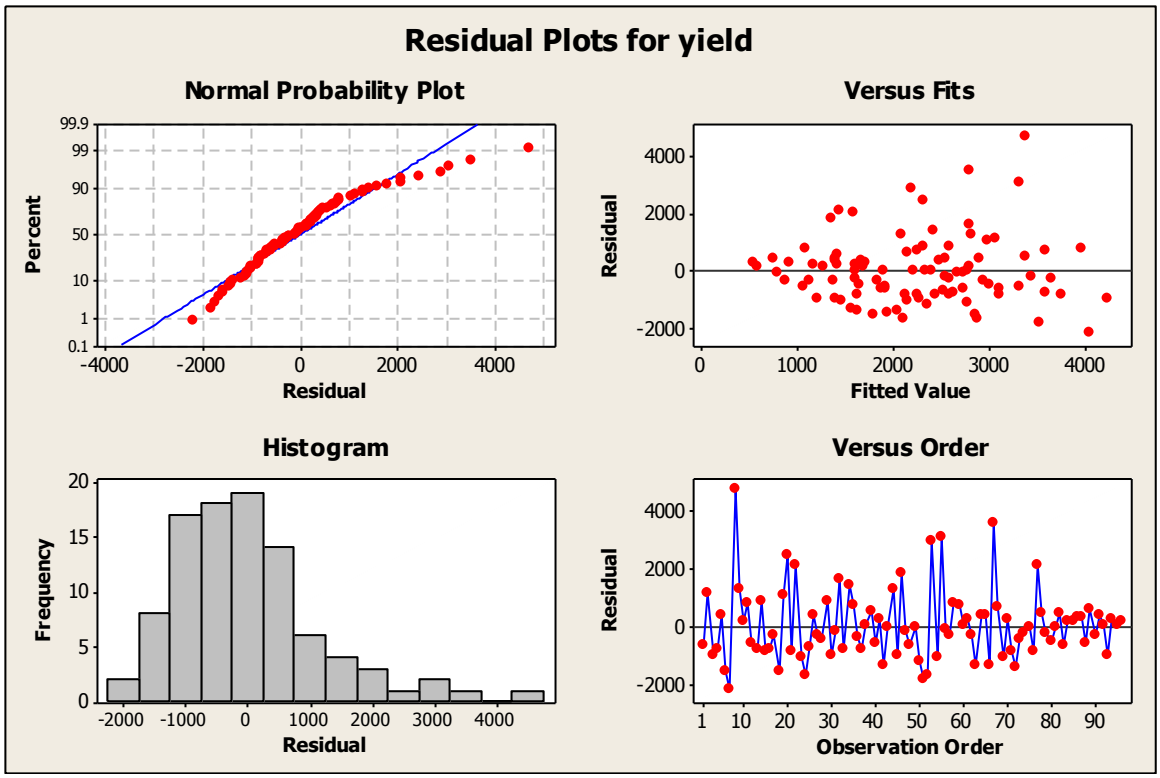


Figure 29. ***Striga*** **emergence farm random, field not nested within farm. Farm as random factor**

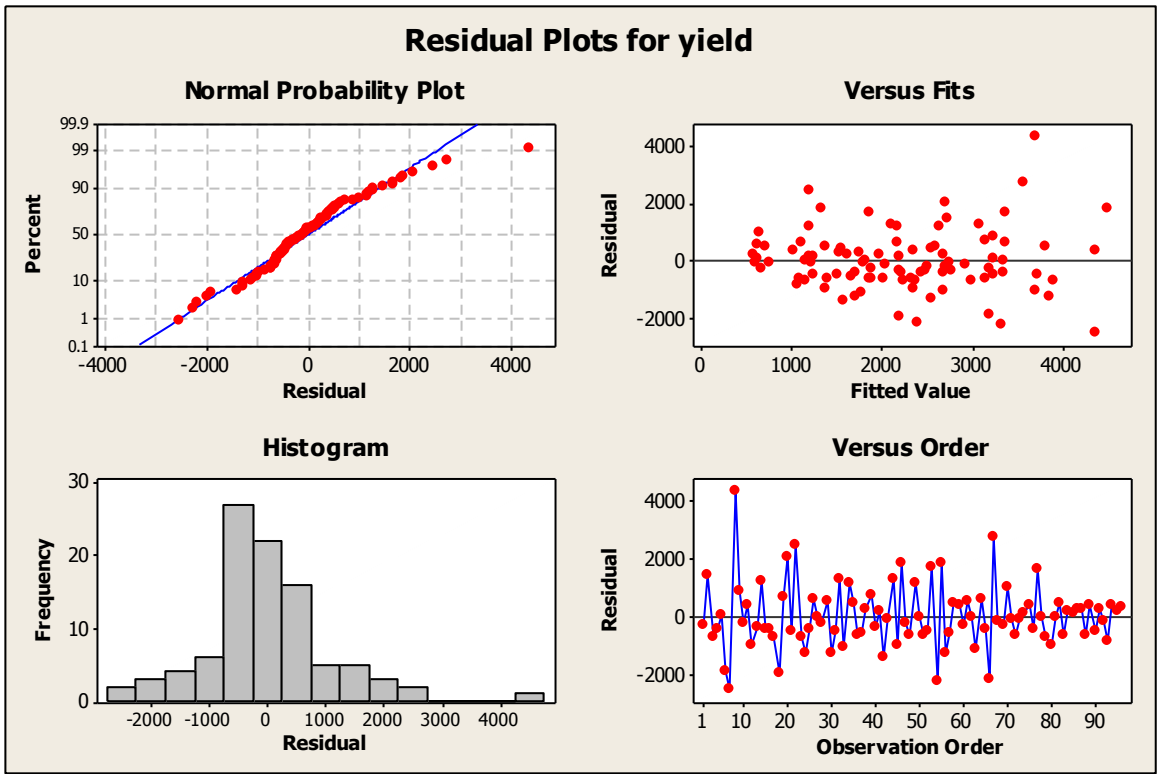


Figure 30. ***Striga*** **emergence for yield, field nested within farm. Farm as random factor.**

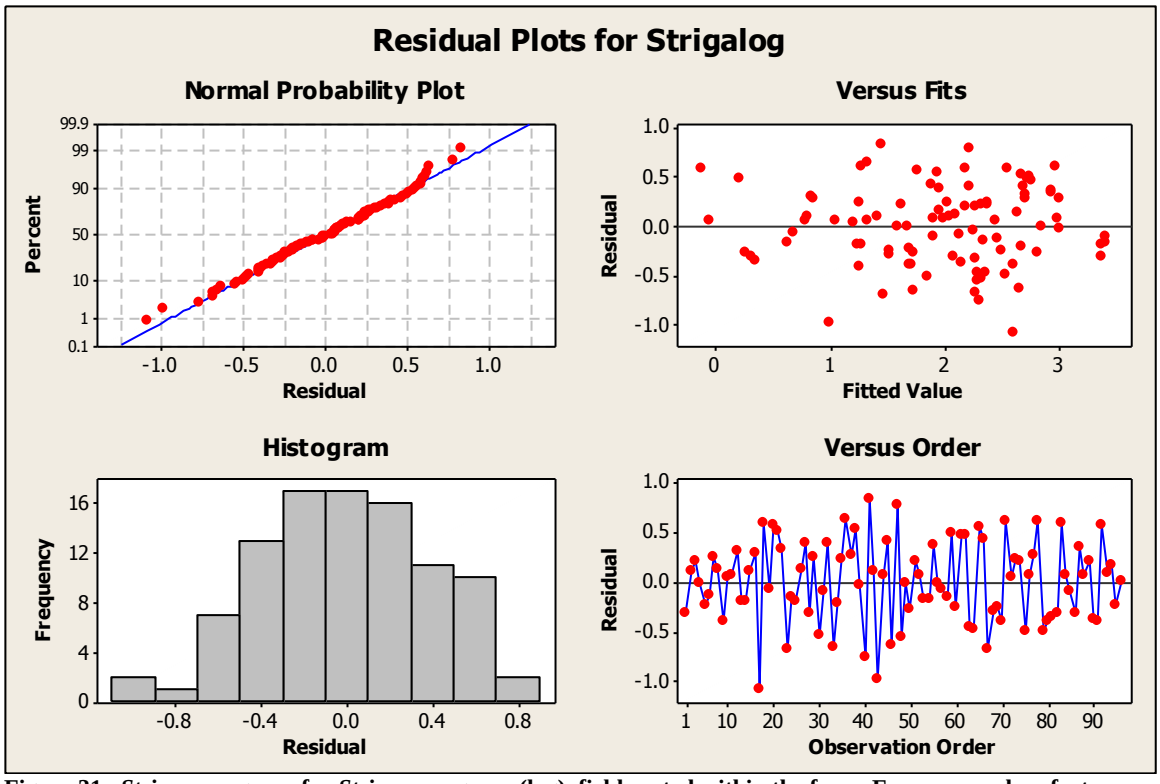


Figure 31. ***Striga*** **emergence for** ***Striga*** **emergence (log), field nested within the farm. Farm as random factor.**

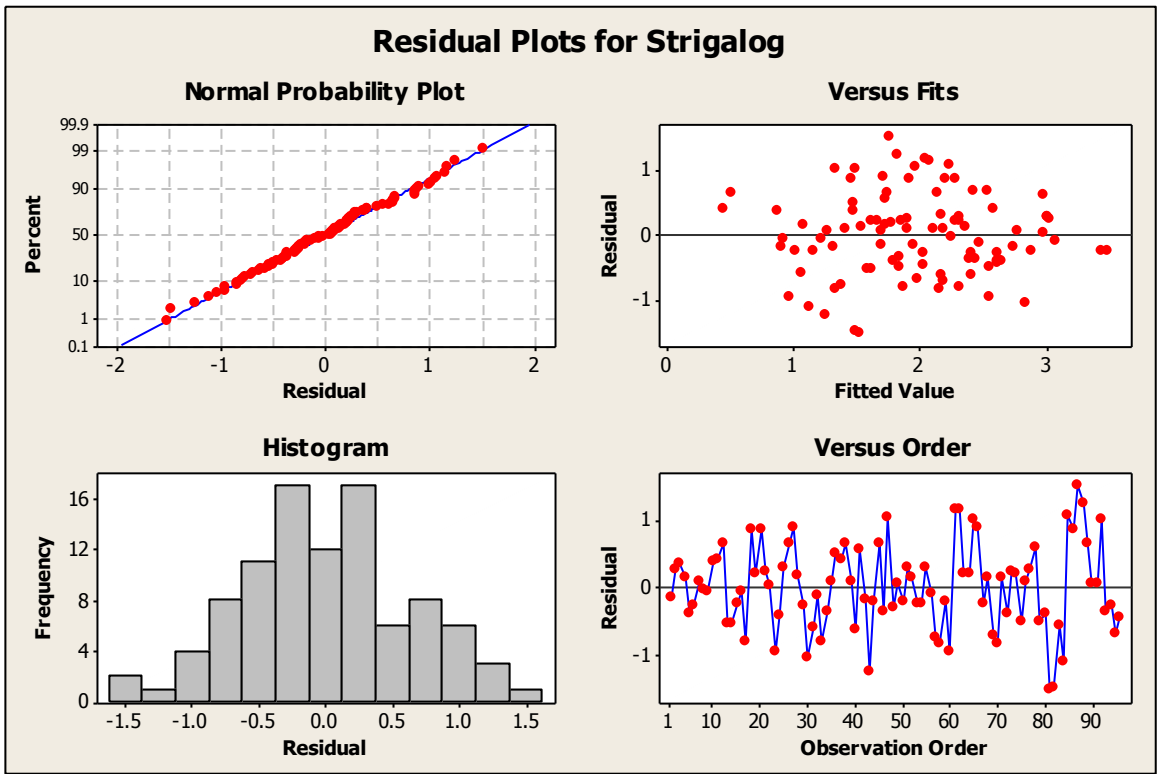


Figure 32. ***Striga*** **emergence of** ***Striga*** **emergence (log). Farm random, field not nested within farm.**

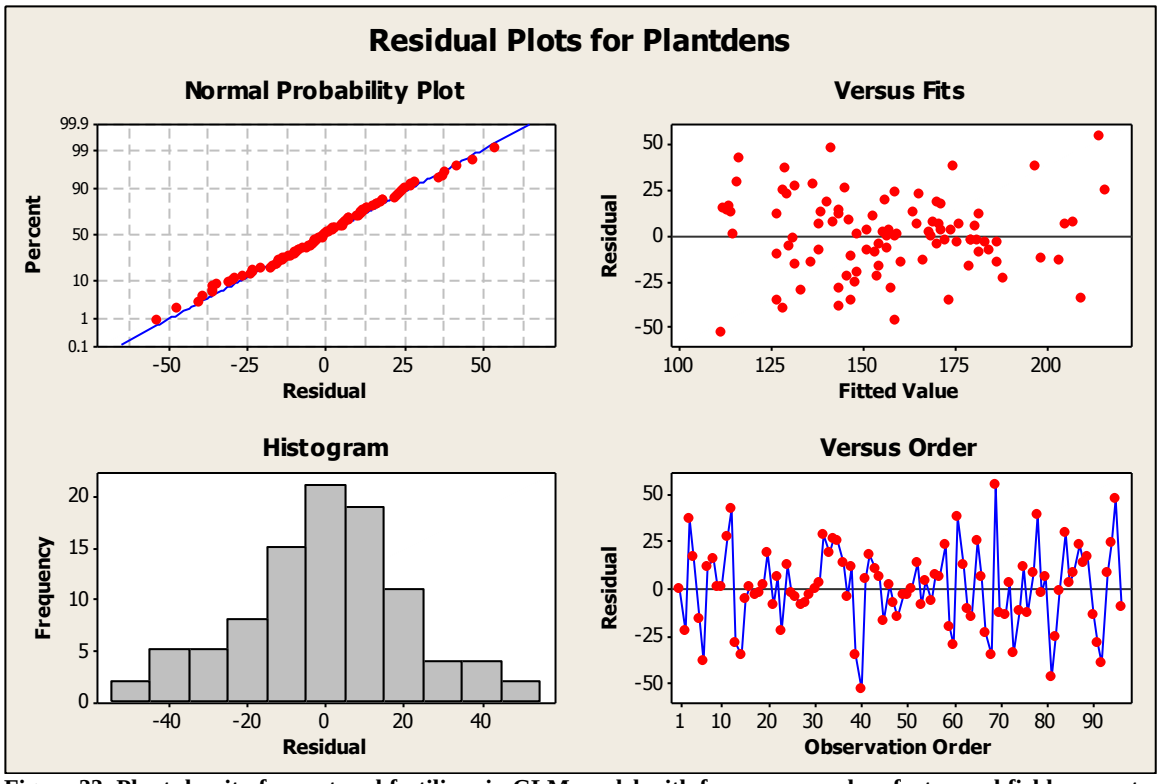
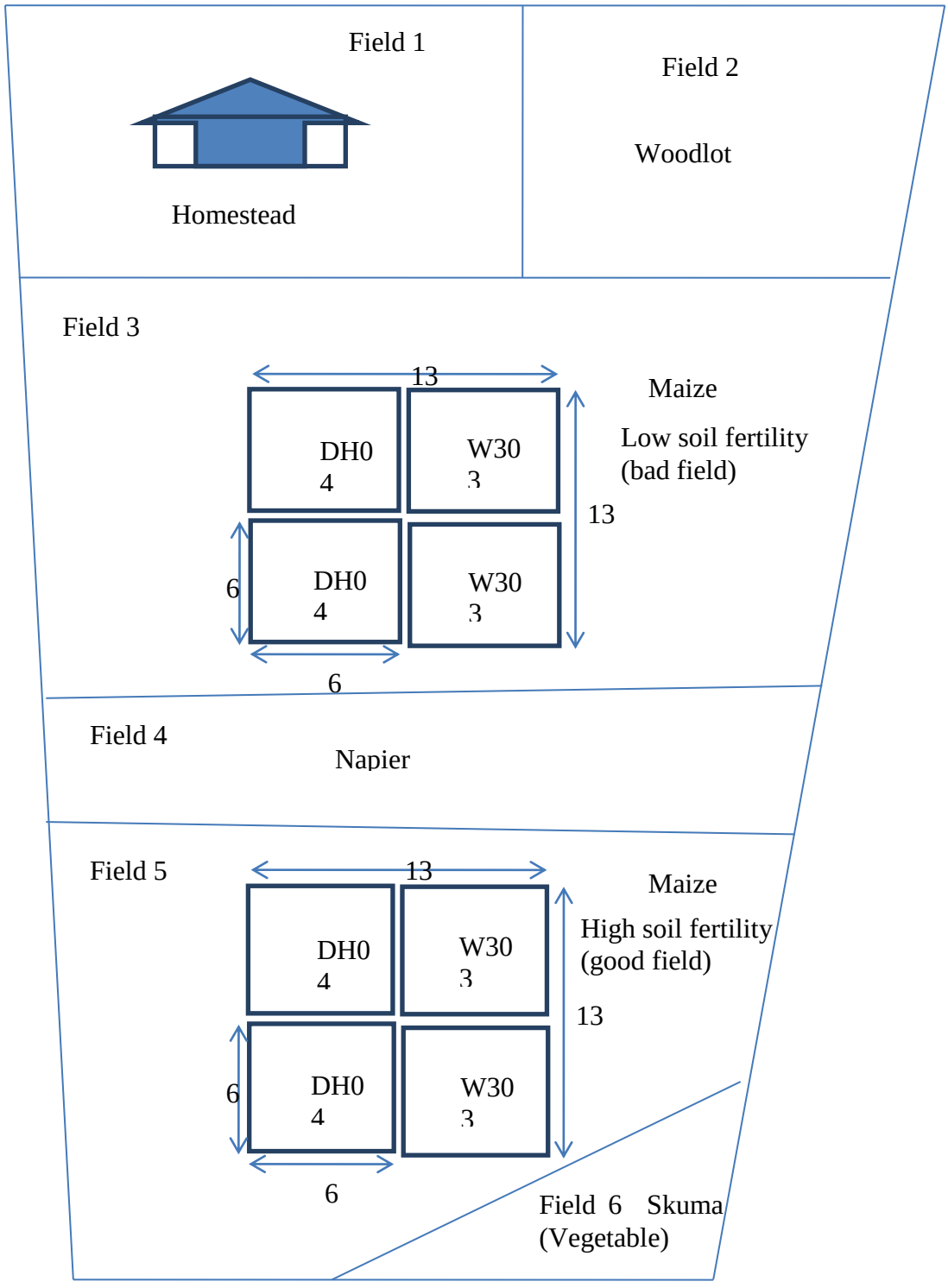


Figure 33. Plant density for sort and fertilizer in GLM model with farm as a random factor and field was not nested within the farm.

9.4 Field trials

Example of homestead and field trial.



9.5 Questionnaire

Striga infestation and Soil Fertility correlations in Western Kenya

Tools needed:

- One questionnaire form
- 1 GPS unit
- Batteries [Pls do some cross-calibration of the GPS units before the survey to be sure they are showing the same readings using the same formats.
- Colour markers (for drawing farm maps)
- Manila sheets
- 1 soil auger
- Bucket for mixing the soil
- Sufficient bags (sugar bags) to store the soil samples [note: soil samples should be stored in double bags with a paper label in between the 2 bags]
- Markers and labels for soil samples
- Clip boards

Procedure:

The interviews and soil sampling will be done by five pairs of enumerators with two enumerators in each pair. The farmer (the household head or his/her spouse) will be interviewed using the questionnaire at his/her homestead. *Please fill with capital letters.*

1) Start by filling section A, B and C on the questionnaire
2) Let the farmer sketch his farm on a manila sheet with colour markers and then copy it to section A7 in the questionnaire.
3) Then the farmer will choose two fields, his/her best and worse field where *Striga* is assumed to be present.
4) Fill section D in the questionnaires for these two specific fields 5) collect soil form these two fields

The soil will be sampled from the chosen fields as follow:

1. Take soil samples at a depth of 0-15 cm
2. Take 10 subsamples per field. When sampling, follow a 'W' in the field
3. Combine the subsamples to one composite sample per field.
4. Mix the soil of the composite sample well.
5. Take a subsample of approximately 1 kg. The exact weight is not important.
6. Label the subsample of soil properly (date, place, field code, name of enumerator, questionnaire number)
7. Store the soil in a double plastic bag with a paper label between the two bags
8. Keep the soils open to allow air-drying pending transport to Maseno.
9. Collect the samples and the questionnaires and give them to Laban

Farm ID:	District/Division	Sub-Location/Village
GPS coordinates farm homestead Latitude (N/S):	Longitude (E/W):	Elevation (altitude):

A. HOUSEHOLD CHARACTERISTIC
A1. Household Composition and Employment
A2. Income
A3. Labour
A4. Livestock Ownership
A5. Household Assets/Resources (wealth indicators)
A6. Purchased Agricultural Inputs
A7. Schematic Map of Farm

B. FARM DESCRIPTION
B1. Soil Cultivation
B2. Other
B3. Crop Management
B4. *Striga* Pressure
B5. Grazing
B6. Field Application
B7. Field Identification

C. FARMER KNOWLEDGE ON *STRIGA*

D. FIELD DESCRIPTION
D1. Field with low soil fertility
D2. Field with high soil fertility

A. HOUSEHOLD CHARACTERISTIC

1. Name of the person interviewed: _____

2. Name of the household head (if not the same as interviewed): _____

3. Sex:_____

4. Age:_____

A1. Household Composition and Employment:

No.	Name	Age	1) Male 2) Female	Schooling level (completed, not just on-going):	Involved in on-farm activities:			Involved in off-farm income generation	
				1) Primary school, 2) secondary school, 3) university, 4) informal education, 5) other, 6) None	Yes, full-time	Yes, but only seasonal	No, not at all	1) Yes 2) No	If yes, what kind of income generating activity/yes? 1-13 (See below this table)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

1) sale of firewood or timber, 2) sale of charcoal, 3) remittances, 4) trading, 5) handiwork (e.g. tailoring), 6) rent, 7) work on other people's fields, 8) food for work, 9) pension, 10) sale of bricks, 11) fish, 12) own business, 13) other [specify if other]……

A2. Income

1. What do **<u>you</u>** consider to be the most important source of household income? Choose one:
Cropping _____ Livestock _____ Off-farm income _____ Remittances _____

2. Can you estimate the portion of the income in your household coming from farming activities and the portion from off-farm sources? Choose what best describes your situation:
- All income from farming _____
- Most from farming, a small part from off-farm sources _____
- About half-half from farming and off-farm _____
- More from off-farm sources and less from farming _____
- No Income from farming, all from off-farm sources _____

[Note: it is not about the <u>amount</u> of money, but for example half-half, or a quarter of the income is generated off-farm, the rest is from farming activities.]

A3. Labour

Do you hire labour for your farm or work in the fields? 1) Yes ____ 2) No ____
If yes, indicate for what kind of activities:

	Tick if yes	In which month(s)?	How long (no. of days) & how many people hired?
Land preparation			
Planting			
Weeding			
Harvesting			
Transport harvest home			
Other:			

(East/Central Africa to include: labour hired for processing bananas)

A4. Livestock Ownership

Which and how many animals do you have and how are they being kept (tethered, free to walk around):

	Number		**Keeping**		
	Owned	**Cared for**	**Free/tethered**		Number:
Cattle (total no.)				Chickens	
Cows for dairy				Guinea fowls	
Oxen				Turkeys	
Sheep				Guinea pigs	
Goats				Rabbits	
Donkeys				Doves/pigeons	
Pigs				Bee hives	
Horse				Fish (fish ponds?)	
				Other:	

A5. Household Assets/Resources (Wealth Indicators)

		If yes, add number			If yes, add number
1	**House: walls**		**7**	**Agricultural tools**	
a	Bricks (burnt)		a	Hoe	
b	Un-burnt bricks or mud bricks		b	Panga/ cutting knife	
c	Poles (bamboo or other), planks		c	Watering cans	
d	Other:		d	Plough	
			g	Ox cart	
2	**House: roof**		h	Tractor	
a	Grass, thatch		i	Other	
b	Iron sheets, asbestos, tin				
c	Tiles		**8**	**Facilities for livestock**	
d	Other (tent)		a	Roofed shelter	
			b	Pen, kraal, fenced place	
3	**House: flooring**		c	Other	
a	Mud				
b	Concrete, cement		**9**	**Storage of harvest**	
c	Tiles		a	Bags	
d	Other:		b	Store	
			c	Other	
4	**Transport**				
a	Bicycle		**10**	**Source of water (domestic use, drinking water)**	
b	Motorbike		a	Private well	
c	Car or pick-up		b	Private borehole	
d	Truck		c	Community borehole	
			d	Tap (piped water)	
5	**Communication**		e	River, stream (surface water)	
a	Cell phone (if yes, total number in household)		f	Others	
b	Radio				
c	Television		**11**	**Irrigation**	
			a	Treadle pump	
6	**Power**		b	Diesel pump	
a	Solar power				
b	Car battery		**12**	**Cooking**	
c	Electricity		a	Wood	
d	Other (ex. paraffin)		b	Charcoal	
			c	Paraffin or kerosine / d. gas	

A6. Purchased Agricultural Inputs

(Please fill table below)

Purchased agricultural inputs	Yes/No	How much per season
Seeds for planting		
Fertiliser		
Manure		
Livestock feed		
Pesticides		
Other (specify_____)		

A7. Schematic map of the farm. Number each field!

Map Instructions: To be drawn by interviewer under farmers' direction; Label each fields (match to fields codes used in Appendixes); Indicate the general direction of slope; Indicate sources of water (well, steam, river) and distance; Show conservation structures, hedges and trees if relevang; Indicate species composition of vegetative conservation structures; Label hedges, trees and conservation structures (hedge = H, tree = T, conservation structures = C); Indicate current crops/fallow; Indicate communal land used (where is it located and area available. Mark if there is any path crossing the fields.

B. FARM DESCRIPTION

B1. Soil Cultivation

1. How is the soil cultivated: _____
2. Which tools are being used:
   _____
3. Who owns the tools: _____
4. Do any other farmers use them: _____

B2. Other

1. Are there any path crossing the field or in the outskirt of the fields: (if yes, please fill in section A7):
   _____

Answer each question for each field.	**Field no.**														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ownership (O=owned; R=rented; C=communal; if rented, specify for how long):															
First taken into cultivation *(give the year)*															
Farmer perception of soil fertility *(High=h, medium=m, low=l):*															
Local name for soil type *(if known):*															
B3. Crop Management															
Is crop rotation being practiced on the farm (if yes, tick which fields.):															
last season:															
coming season:															
Maize and/or sorghum is commonly grown *(tick which fields):*															
B4. *Striga* Pressure															
***Striga* pressure on the** field (N=no *Striga*, L=little, M=medium, H=high)															
B5. Grazing															
Have livestock access to graze on the fields (if yes tick):															

B6. Field Application

2. Do you add fertilizer, manure or crop residues on your field (type and amount for the last season):

		Ferilisers		Manure		Crop Residues
Field no.	**Crop or crop associations (indicate major and minor crops if intercropped)**	**Type**	**Amount**	**Type**	**Amount**	**Left in the field or exported.**

B7. Field Identification

Fields that commonly are planted with cereals such as maize and/or sorghum will be filled in this table (ex. Field 1 have low soil fertility according to the farmer and at the same time little *Striga* pressure and therefore a 1 is put in the first block):

	Low Soil Fertility	Medium Soil Fertility	High Soil Fertility
Little *Striga* Pressure			
High *Striga* Pressure			

1. Which is the best respectively worst field on the farm, where maize is commonly grown (to be filled using the table above): _____

_____

C. FARMER KNOWLEDGE ON *STRIGA*

1. For how long (years) have you had *Striga* on the farm (no. of years): _____
2. Has it expanded since the first time you noticed it (if yes, how much and where on the farm): _____
3. Do you have *Striga* on all fields? _____
4. Which fields have more *Striga[**1**=fields near house, **2**=fields furthest from the house; **3**=fields in the middle; **4**=other, specify:_____]:_____ _____ _____
5. Which technology have you been testing?

(Use this table to answer question 5)

***Striga* control technology**	**Aware of the technology? Yes=1 No=0**	**If aware, current use status Currently using=1 Abandoned=2 Never adopted=3**	**If currently using, what is the yield per acre under that technology?***	**Number of years since adoption**
Imazapyr (herbicide) Resistant (IR)-Maize variety (UaKayongo)				
Striga-resistant maize (KSTP 94)				
Striga-resistant maize (WS 909)				
Striga-resistant maize (KSTP 94) grown with legumes				
Striga-resistant maize (WS 909) grown with legumes				
Intercropping of legumes followed by cassava/Desmodium (Maize in the 3rd year)				
Push-Pull (Maize-Desmodium strip cropping)				
Traditional practice (manuring,)				
Traditional practice (uprooting,)				
Traditional practice (uprooting and burning)				
Traditional practice (uprooting and removing from the field)				

***Only applicable for farmers who have used the technology for more than one season**

6. If you are aware of any above modern *Striga* control technology but have not adopted any, what is the most important reason for non-adoption? (Circle one only)

i) Gathering more information about the technology
ii) Too risky to adopt
iii) Lack of improved seeds (*Striga*-resistant varieties)
iv) Traditional control practice is better
v) Cash constraint to buy seeds and other inputs
vi) Others (e.g. cultural factors)

D. FIELD DESCRIPTION + SOIL SAMPLING

D1. Field with low soil fertility

(This table should only be filled out for fields grown with maize in the current or previous season, and where the farmer has indicated *Striga* is present. All questions on crops and inputs used should be asked for a specific season, best = the last season)

FIELD CODE FROM SCHEMATIC MAP A7 :		
GPS coordinates and altitude of centre of field:		
altitude: m.a.s.	**S**	**E/W**
Sketch field shape and number each corner:		
GPS coordinates of the corners of the field:		
Corner 1:	**S**	**E/W**
Corner 2:	**S**	**E/W**
Corner 3:	**S**	**E/W**
Corner 4:	**S**	**E/W**
Corner 5:	**S**	**E/W**
Corner 6:	**S**	**E/W**
Corner 7:	**S**	**E/W**
Corner 8:	**S**	**E/W**
Corner 9:	**S**	**E/W**
Corner 10:	**S**	**E/W**
Attached / detached from the main homestead land area *(A=attached; D=detached)*		
Position of field(P=plateau; U=upperslope; M=midslope; D=downslope; V=valley bottom; other: specify)		
Slope (give in degrees, using a clinometer)		
Drainage (P=poor, G= good, E=excessive):		
Slope class on the farm (F=flat, S=steep, V=very steep):		
Visible erosion (1=no erosion, 2=moderate erosion, 3=severe erosion):		
Farmers estimation of soil fertility (1=fertile, 2= slightly fertile, 3=poor soil):		
Flooded > 4 months yr-[1]*(Yes/No)*		
Presence of rocks, stones or gravel on the surface (Rock scale 1=0-5%; 2=5-25%; 3=25-50%; 4=50-75%;		

5=75-95%; 6=95-100%)		
Soil hard-setting (None = 0, temporary = t, Permanent = p)		
Water harvesting techniques (0=none; PP=planting pits (Zai); R=ridges; TR=tied ridges; HM=half moons; other: specify)		
Presence of conservation structures (0=none; V=vegetation; S=structural; both=VS)		
Type of conservation structures(for vegetation structures, specify the main species used; for other structures, specify the type: stone rows; fanyajuu; fanyachini; terraces; others: specify)		
Main crop production constraint (E=erosion; F=low fertility; W=weeds; PD=pests & diseases; S=stones; other: specify)		
Crops presently in the field (give more than 1 if association)		
Crop in previous season (give more than 1 if association)		
Crop for next season (give more than 1 if association)		
If fallow, for how many years? *(add number of years)*		
Land preparation (0=no tillage; H=hoe-tilled; P=ploughed; other: specify)		
Presence of *Striga* (approximate % of area covered with *Striga*)		
Presence of weeds - dominant type(grass, broad leaf, others: specify)		
Utilization of inputs (0=nothing; F=fertilizer; OM=organic material; OMF=both)		
If fertilizer applied, give type and rate (in local units; specify weight of local unit)	**type:**	
give time of application (P=at planting; other: specify)		**rate:**
manner of application (BCI=broadcast and incorporated; BL=banded in or near the line; PP=point-placed; other: specify)		
If OM applied, give type and rate (in local units; specify weight of local unit)	**type:**	
give time of application (P=at planting; T=before planting during tillage A=any time; other: specify)		**rate:**
manner of application (BC=broadcast; BCI= broadcast and incorporated; BL=banded in or near the line; PP=point-placed; other: specify)		
Was there insecticide or herbicide applied *(N=no; Y=yes)*		
If pesticide, give type (L=local; specify; C=purchased chemical; other: specify)		

D2. Field with high soil fertility

(This table should only be filled out for fields grown with maize in the current or previous season, and where the farmer has indicated *Striga* is present. All questions on crops and inputs used should be asked for a specific season, best = the last season)

FIELD CODE FROM SCHEMATIC MAP A7 :		
GPS coordinates and altitude of centre of field:		
altitude: m.a.s.	**S**	**E/W**
Sketch field shape and number each corner:		
GPS coordinates of the corners of the field:		
Corner 1:	**S**	**E/W**
Corner 2:	**S**	**E/W**
Corner 3:	**S**	**E/W**
Corner 4:	**S**	**E/W**
Corner 5:	**S**	**E/W**
Corner 6:	**S**	**E/W**
Corner 7:	**S**	**E/W**
Corner 8:	**S**	**E/W**
Corner 9:	**S**	**E/W**
Corner 10:	**S**	**E/W**
Attached / detached from the main homestead land area *(A=attached; D=detached)*		
Position of field(P=plateau; U=upperslope; M=midslope; D=downslope; V=valley bottom; other: specify)		
Slope (give in degrees, using a clinometer)		
Drainage (P=poor, G= good, E=excessive):		
Slope class on the farm (F=flat, S=steep, V=very steep):		
Visible erosion (1=no erosion, 2=moderate erosion, 3=severe erosion):		
Farmers estimation of soil fertility (1=fertile, 2= slightly fertile, 3=poor soil):		
Flooded > 4 months yr-1*(Yes/No)*		
Presence of rocks, stones or gravel on the surface (Rock scale 1=0-5%; 2=5-25%; 3=25-50%; 4=50-75%; 5=75-95%; 6=95-100%)		
Erosion visible (None=0; sheet=S; Rill=R;		

Gully/Mass=G)		
Soil hard-setting (None = 0, temporary = t, Permanent = p)		
Water harvesting techniques (0=none; PP=planting pits (Zai); R=ridges; TR=tied ridges; HM=half moons; other: specify)		
Presence of conservation structures (0=none; V=vegetation; S=structural; both=VS)		
Type of conservation structures(for vegetation structures, specify the main species used; for other structures, specify the type: stone rows; fanyajuu; fanyachini; terraces; others: specify)		
Main crop production constraint (E=erosion; F=low fertility; W=weeds; PD=pests & diseases; S=stones; other: specify)		
Crops presently in the field (give more than 1 if association)		
Crop in previous season (give more than 1 if association)		
Crop for next season (give more than 1 if association)		
If fallow, for how many years? *(add number of years)*		
Land preparation (0=no tillage; H=hoe-tilled; P=ploughed; other: specify)		
Presence of *Striga* (approximate % of area covered with *Striga*)		
Presence of weeds - dominant type(grass, broad leaf, others: specify)		
Utilization of inputs (0=nothing; F=fertilizer; OM=organic material; OMF=both)		
If fertilizer applied, give type and rate (in local units; specify weight of local unit)	**type:**	**rate:**
give time of application (P=at planting; other: specify)		
manner of application (BCI=broadcast and incorporated; BL=banded in or near the line; PP=point-placed; other: specify)		
If OM applied, give type and rate (in local units; specify weight of local unit)	**type:**	**rate:**
give time of application (P=at planting; T=before planting during tillage A=any time; other: specify)		
manner of application (BC=broadcast; BCI= broadcast and incorporated; BL=banded in or near the line; PP=point-placed; other: specify)		
Was there insecticide or herbicide applied *(N=no; Y=yes)*		
If pesticide, give type (L=local; specify; C=purchased chemical; other: specify)		