# INFLUENCE OF SOIL FERTILITY MANAGEMENT ON *STRIGA* REPRODUCTION AND GRAIN YIELD OF SORGHUM IN SEMIARID AREAS OF TANZANIA

**KUDRA, ABDUL**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN DRYLAND RESOURCE MANAGEMENT**

**DEPARTMENT OF LAND RESOURCE MANAGEMENT AND AGRICULTURAL TECHNOLOGY, FACULTY OF AGRICULTURE, COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES, UNIVERSITY OF NAIROBI**



**2011**

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2011

# DECLARATION

I hereby declare that this thesis is my original work and has not been submitted for a degree in any other university.

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This thesis has been submitted with our approval as university supervisors

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## DEDICATION

To almighty God, it is all because of you, for you made it possible

# ACKNOWLEDGMENTS

After counting thousands of plants and seed capsules and millions of seeds, apparently endless analysis, writing and re-writing we are finally there. However, I am pleased not only because it is completed, but because I have now seen *Striga* in its broadest possible perspective. Now is the time to thank the people who, directly or indirectly, helped me to complete this thesis.

Special thanks are due to my supervisors, Dr. G. N. Chemining'wa, Prof. K. P. Sibuga and Dr. R. N. Onwonga for their support, lasting patience and more importantly the latitude and leaving me to work independently during my thesis work. Special thanks to my family, for the support during the entire period of this study.

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I am thankful to the Sokoine University of Agriculture (my employer) for permitting me to go on study leave, supporting and offering me laboratory space to carry out the research project. I want here to express my gratitude to the staff of the University of Nairobi, Faculty of agriculture, especially Prof. Kinuthia Ngugi for all the arrangements with regards to travel and my stay in Nairobi.

Last but not least, I would like to express my gratitude and thanks to my sponsor RUFORUM for financial support that enabled me to pursue a PhD degree in Dryland Resource Management at the University of Nairobi.

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| % | Percent |
| $^0C$ | Degree centigrade |
| ANOVA | Analysis of variance |
| AOAC | Association of Official Analytical Chemists |
| Ca | Calcium |
| CEC | Cation exchange capacity |
| CIMMYT | International maize and wheat improvement centre |
| CV | Coefficient of variation |
| Cu | Copper |
| Fe | Iron |
| Fig. | Figure |
| FYM | Farmyard manure |
| IITA | International Institute of Tropical Agriculture |
| ISM | Integrated *Striga* management |
| K | Potassium |
| KCl | Potassium chloride |
| kg N/ha | Kilogram of nitrogen per hectare |
| LSD | Least significant difference |
| $m^2$ | Square meter |
| Mg | Magnesium |
| mm | Millimeter |
| MPa | Moisture /water potential |
| NS | Not significant |
| OC | Organic carbon |
| P | Phosphorus |
| pH | Potential of hydrogen |
| $R^2$ | Regression coefficient |
| RCBD | Randomized complete block design |
| SED | Standard error of difference |
| SPSS | Statistical package for social sciences |
| t/ha | Ton per hectare |
| TSP | Triple-superphosphate |
| URT | United Republic of Tanzania |
| WAP | Week after planting |
| Zn | Zinc |

# GENERAL ABSTRACT

**Kudra A., 2011**. Influence of soil fertility management on *Striga* reproduction and sorghum grain yield in semiarid areas of Tanzania. PhD thesis, Faculty of Agriculture, University of Nairobi.

Witchweed (*Striga*), a root parasite, has become a major biological constraint to sorghum production with severe yield losses of about 85% reported in semi-arid areas of sub-Saharan Africa. In Tanzania, *Striga asiatica* is the most dominant *Striga* species and covers over three quarters of the country, from the northern parts to the southernmost regions. The success of this weed is due to its ability to produce large numbers of tiny dust-like seeds that cause a rapid increase in parasite population density after the first infestation. A long-term control program must focus on reducing *Striga* seed inputs into the soil sufficiently so that a reasonable crop yield can be obtained. Therefore a study was carried out in two regions of Tanzania with the following specific objectives: (a) to determine the agronomic practices adopted by farmers in *Striga* control and the relationship between soil chemical characteristics and *Striga* reproduction; (b) to determine the influence of organic and inorganic fertilizers on *Striga asiatica* reproduction and sorghum grain yield; and (c) to evaluate the effect of combined farmyard manure and urea on *Striga asiatica* reproduction and sorghum grain yield.

Surveys were carried out in 20 farmers' fields in 2010/2011 cropping season in semi arid areas of Dodoma and Morogoro regions for the first objective. Data collected included the agronomic practices used by farmers in *Striga* control, soil chemical characteristics, *Striga* plant counts and

number of capsules/*Striga* plant. A semi-structured questionnaire was used to generate information on the cropping practices, farmers' knowledge and perceptions of the *Striga* problem and agronomic practices adopted by farmers for *Striga* control. Soils were sampled at 0 - 20 cm depth from different farmers' fields and analyzed for soil moisture content, pH, organic carbon, nitrogen, phosphorus and potassium. The trials for the second objective were conducted in two consecutive years (2009/2010 and 2010/2011) at Hombolo Research Station in Dodoma region. Treatments consisted of farmyard manure (5.9 tons/ha), chicken manure (2.5 tons/ha), urea (50 kg N/ha) and triple superphosphate (TSP) (40 kg P/ha) which were evaluated on sorghum (variety Macia) in a field naturally infested with *Striga asiatica* (L.) Kuntze). The 5.9 tons/ha farmyard manure and 2.5 tons/ha chicken manure tested were each equivalent to 50 kg N/ha. A randomized complete block design with four replications was used. The trials for the third objective were carried out in 2010/2011 at Hombolo and Melela locations in Dodoma and Morogoro regions respectively. A factorial experiment in a randomized complete block design was set up in fields naturally infested with *Striga asiatica*. The treatments which comprised farmyard manure at rates equivalent to 0, 25, 50, 60 kg N/ha and urea at rates of 0, 25, 50 and 60 kg N/ha were replicated three times.

Results from the surveys showed that the recommended agronomic practices for the control of *Striga* have not yet found large scale application on farmers' fields. The majority of farmers indicated that *Striga* infestation in the area was increasing and they were not able to control in their fields. Two species of *Striga* (*Striga siatica* and *Striga forbesii*) were observed in the farmers' fields, although *Striga asiatica* was the dominant species. Potassium was highly positively related to the number of capsules/*Striga* plant. This study also showed that fertilizer

applications indeed affected *Striga* reproduction negatively. Plants supplied with chicken manure, urea and TSP had significantly fewer number of capsules per plant than farmyard manure treated and control (without fertilizer application) plants. Combination of urea at 50 kg N/ha or 60 kg N/ha with all rates of farmyard manure significantly reduced the number of capsules/*Striga* plant. Generally, fertilizer applications improved sorghum grain yield with chicken manure giving significantly the highest grain yield. Combined application of urea and farmyard manure increased sorghum grain yield compared to the application of either urea or farmyard manure alone. Economic analyses showed that the marginal rates of return from applying urea alone at 25, 50 and 60 kg N/ha were 31, 54 and 48% respectively. Combination of urea at 60 kg N/ha and FYM at 60 kg N/ha equivalent had the highest marginal rate of return (70%). Farmyard manure alone at 25, 50 and 60 kg N/ha equivalent rates had lower rates of returns than the non-treated control.

Chicken manure and combined farmyard manure with urea can be used to improve sorghum production in semiarid arid areas of Tanzania. Low quantities of FYM and high soil K may promote *Striga* infestation as they are associated with increased *Striga* reproduction. Even though fertilizers play a significant role in *Striga* reproduction, calculations of seed production per capsule indicated that considerable amounts of seeds were still added to the soil. Therefore, the use of fertilizers alone is not enough to reduce the seed inputs and seed bank. This calls for an integrated approach in which cultural, chemical and crop resistance strategies are deployed.

# OUTLINE OF THE THESIS

General Abstract: Giving a concrete synthesis of the study and capturing the key findings.

Chapter 1 General introduction: Showing a major problem of the study, the significance of the study and how the study fills research gaps identified.

Chapter 2 literature review: Represents the critical points of current knowledge including *Striga* biology, factors contributing to its aggressiveness and control options, fertilizer influence on *Striga* infestation and physical-chemical characteristics of the *Striga* infested soils.

Chapter 3: Presents the agronomic practices adopted by farmers for *Striga* control in semi arid areas of Tanzania on the basis of field surveys. The influence of soil physical-chemical properties on *Striga* reproduction is critically evaluated.

Chapter 4: Presents the potential effect of different sources of fertilizers on *Striga* seed production, sorghum grain yield and improvement of soil fertility in a field study. The long-term effects of fertilizers on *Striga* seed bank are discussed.

Chapter 5: Presents the effect of combined application of farmyard manure and urea on *Striga* reproduction and sorghum performance.

Chapter 6: The overall discussion and conclusions of the study are presented.

# CHAPTER 1

## GENERAL INTRODUCTION

### 1.1 Background information

Sorghum [*Sorghum bicolor* L. (Moench)] is ranked fifth in importance among the world's cereals after rice, wheat, barley and maize. Sorghum is a drought resistant crop and is adapted to a wide range of ecological conditions which are unfavourable to other cereals. For example, extremely high temperatures which injure maize pollen and result in poorly filled ears are not equally injurious to sorghum (Bayu *et al.*, 2001). During periods of extreme drought the plant becomes somewhat dormant but growth resumes when moisture becomes available.

The water requirement of dry matter produced by sorghum is considerably less than that of maize and most other grain crops (Shiringani, 2005). Because of its low water requirement and ability to withstand drought, sorghum can be grown during short rains (Kwacha, 2001). Sorghum has important usage to human and animals. It can be consumed as leavened bread, thick porridge and snacks. Sorghums also have a number of important industrial uses including production of beer, adhesives, dye, resins, ethanol, feed and fuel.

Sorghum is largely grown in low rainfall areas of Tanzania including Dodoma, Morogoro, Tabora and Singida regions (Kwacha, 2001). However, the production of this important crop is threatened by biotic and abiotic constraints (Bayu *et al.*, 2001). A major biotic pest of sorghum in Africa is the parasitic plant of the genus *Striga* (Ayongwa *et al.*, 2006). Witchweed (*Striga*), a root parasite, has become a major biological constraint to cereal production with severe yield losses of about 85% reported in semi-arid areas of sub-Saharan Africa (Rodenburg, 2005). *Striga asiatica* and *Striga hermonthica* are the most prevalent species attacking cereals in Africa (Van Mourik, 2003).

Recent studies show that *Striga* infestation is becoming a big problem in the production of sorghum, maize, rice and millet, which are the major cereal crops grown in the tropics (Westerman *et al.*, 2007; Gressel and Velverd, 2009). Further, *Striga* has been reported to occur where it was not previously known. Ecological models have also predicted that climate change may result in the spread of *Striga* into new areas (Mohamed *et al.*, 2006).

The success of the witch weed is brought about by its ability to produce large numbers of tiny dust-like seeds that cause rapid increase in parasite population density after the first infestation (Ransom, 2000). Tremendous progress has been made towards understanding the *Striga* biology, physiology and ecology following many years of intensive studies. Nonetheless, control methods have been less impressive in sub-Saharan Africa (Pageau *et al.*, 2003).

The control options most commonly employed are agronomic, chemical and use of *Striga* resistant varieties and are also grouped into direct and indirect methods (Oswald *et al.*, 2002). Direct methods include the use of *Striga* resistant varieties and chemicals which attack the parasites directly and have an immediate effect on *Striga* but not always on crop yields (Oswald, 2005). Chemical control options are costly and beyond the means of poor subsistence farmers in sub-Saharan Africa. The indirect *Striga* control methods comprise soil fertility management, intercropping and crop rotation (Oswald and Ransom, 2001). The indirect methods require several cropping seasons before an effect can be observed, but they control *Striga* in a sustainable way and increase crop yields over time (Oswald, 2005). Against this backdrop, a study was conducted in east and central drylands of Tanzania to determine the influence of soil fertility management strategies on *Striga* reproduction and sorghum grain yield.

## 1.2 Problem statement

Tanzania is ranked as one of the most highly *Striga* infested countries in terms of area in East Africa, with infestation reported almost throughout the entire country. The area under *Striga* is estimated to be 963,500 hectares (Gressel and Velverd, 2009) with the highest severity found along the Lake Victoria in the Mwanza and Mara regions. Tanzania's *Striga* infestation levels are in the medium to high severity ranges, particularly in the central semi-arid region and the southern part of the country (MacOpiyo *et al.*, 2010).

Semi-arid areas of Tanzania lie in a zone where the most significant *Striga* species (i.e. *Striga asiatica*, *S. hermonthica* and *S. forbesii*) which infest cereals occur (Mbwaga, 2001). Grain yield losses from parasitized cereal crops are difficult to estimate due to different infestation levels but reports have shown losses of 5-30% or total crop failure in heavily infested sites (Mbwaga, *et al.*, 2007). These semi arid regions are often characterized by low rainfall and infertile soils. The impact of *Striga* is, therefore, compounded by its predilection for attacking crops already under moisture and nutrient stress (Ejeta, 2007).

So far, there is no single control option that is efficient in controlling this weed. *Striga*-infested areas have very high levels of long-lived dormant seeds in the soil (Matusova *et al.*, 2004, 2005). Therefore, infestation by *Striga* becomes worse in each successive year, contributing to increased poverty and starvation (Ouattara *et al.*, 2006). Some fields have become so heavily infested with *Striga* that farmers are forced to abandon them (Ahonsi *et al.*, 2004). Every year *Striga* damage to crops accounts for an estimated US$7 billion in yield loss in sub-Saharan Africa and affects the welfare and livelihoods of over 100 million people (Dugje *et al.*, 2008).

The measures for *Striga* management are hampered by a unique survival strategy of the weed, whereby it produces large amount of seeds which may be dispersed by wind, water, animal and human activities (Parker, 2009). One mature *Striga* plant is capable of producing up to 200000 seeds (Ayongwa, 2011). Therefore, prevention of further build ups of the *Striga* seed bank through control measures remains an essential component in *Striga* management. However, from the available literature *Striga* seed production and control measures have been related in few studies (Rodenberg *et al.*, 2006a; Van Mourik, 2007).

In a study, Van Mourik (2007) stated that perhaps the most unexplored area of *Striga* research is the role of fertilizer application on *Striga* seed production and its long-term effect on seed bank. The author further noted that an initial increase in *Striga* recruitment and seed bank might be expected due to an increase of the carrying capacity of host plants with increased nutrient availability. An increase in *Striga* emergence due to nitrogen fertilization was suggested to be associated with increased vigor of the host crop which may increase its carrying capacity to support higher number of *Striga* parasites (Igbinnosa *et al.*, 1996; Pieterse and Verkleij, 1991).

Therefore, the current study would provide critical information through determining the various effects that fertilizer application could have on *Striga* reproduction. More specifically to understand how both organic and inorganic fertilizers influence *Striga* seed production and long-term effects on *Striga* seed bank and sorghum grain production.

### 1.3 Justification

*Striga* infestation occurs in semi arid areas of Tanzania where the poor farmers reside and hunger prevails. These regions are often characterized by low rainfall and low soil fertility. Therefore, control of *Striga* and improvement in soil fertility will enhance crop productivity in semi arid areas of Tanzania.

Most studies on *Striga* management have focused on the reduction of the number of emerged *Striga* plants and improving host yields. The success of a control option is generally assessed by measuring the reduction in the number of emerged *Striga* shoots compared to a control treatment. This observation of the number of emerged plants gives an indication of the *Striga* pressure but does not give information on seed production and long-term effects on the *Striga* seed bank.

As the *Striga* seed bank plays an important role in *Striga* plant population dynamics, it is important to know the effects of the available control options on *Striga* seed production and long term effect on seedbank. Assessing the influence of fertilizers on *Striga* reproduction will provide information that can be used to develop long term integrated *Striga* management strategies targeted at reducing the *Striga* seed bank and improving the host yield.

Since soil fertility decline is linked with the build-up of *Striga*, an approach that looks only at controlling *Striga* while neglecting the need for improving soil fertility would do little to restore on-farm productivity and make farming sustainable. Without effective soil fertility management farmers would attain low yields even at low *Striga* levels. Therefore, *Striga* control strategies that improve soil fertility will be economically feasible to farmers, hence high have chances of adoption.

## 1.4 Objectives

### Overall objective

The overall objective of the present study was to determine the influence of soil fertility management on *Striga* seed bank dynamics and sorghum grain yield in semi arid areas of Tanzania

### Specific objectives

The specific objectives of the study were:

1. To identify agronomic practices adopted by farmers in *Striga* control and the relationship between soil chemical characteristics and *Striga* reproduction
2. To determine the influence of different sources of nutrients on *Striga asiatica* reproduction and sorghum grain yield
3. To determine the effect of combined farmyard manure and urea on *Striga asiatica* reproduction and sorghum grain yield

## 1.5 Hypotheses

The following hypotheses were investigated:

1. Agronomic practices and soil chemical characteristics greatly influence *Striga* reproduction
2. Different sources of nutrients have different effect on *Striga* reproduction and sorghum grain yield
3. *Striga* reproduction and sorghum grain yield are dependent on the level of organic and mineral fertilizers applied

# CHAPTER 2

## LITERATURE REVIEW

### 2.1. *Striga* problem in East Africa (Tanzania, Kenya, Uganda)

The most dominant species of *Striga* in east Africa are *Striga hermonthica* (Del.) Benth, *Striga asiatica* (L.) Kuntze, and *Striga forbesii* Benth. Of the three species, *S. hermonthica* is the most dominant in the Lake Victoria Basin of Kenya, Uganda and Tanzania (Mbwaga, 2002). *Striga hermonthica* (Del.) Benth is also quite extensive in geographical coverage and occurs across a vast range of ecological environments within Uganda and Kenya. In Tanzania, however, *Striga asiatica* is the most dominant *Striga* species and covers over three quarters of the country, from the northern parts of the country to the southernmost regions. Widespread occurrence of *Striga asiatica* can also be observed along the Kenyan coast (MacOpiyo *et al.*, 2010).

### 2.2. The genus *Striga*

The most important parasitic plant species in Africa belong to the genus *Striga* of the family Scrophulariaceae. Members of this genus are obligate annual hemiparasites. They are chlorophyllous, but require a host to complete their life cycle (Dugje *et al.*, 2006). Although 30 or more species of *Striga* have been described, only five are presently of economic importance in Africa (Berner, *et al.*, 1997). These are, in approximate order of economical importance, *Striga hermonthica* (Del.) Benth., *Striga asiatica* (L.) Kuntze, *Striga gesneroides* (Willd.) Vatke, *Striga aspera* (Willd.) Benth., and *Striga forbesii* Benth. All except *Striga gesneroides* are parasites of Africa's cereal crops namely sorghum, millet, maize and rice (Lendzemo, 2004).

*Striga gesneroides* is a parasite on cowpea and other wild legumes (Mohamed *et al.*, 2001). By parasitizing crop species, *Striga* species can cause substantial yield losses and are therefore considered agricultural pests. *Striga asiatica* occurs throughout Africa, Arabia and Asia. *Striga gesneroides* is found in the same region although its distribution is concentrated in sub-Saharan Africa. Both *S. asiatica* and *S. gesneroides* have a self compatible reproduction system. *Striga hermonthica* is an obligate out crosser and occurs only in Africa (Van Mourik *et al.*, 2005).

*Striga* occurs in sub-tropical areas with an annual rainfall ranging from 300 to 1200 mm. However, it may be able to adapt to agro-climatic conditions outside its current distribution range and to other crop species (Mohamed *et al.*, 2006). Unlike from other weeds, *Striga* at emergence develops numerous thin adventious roots that attach to the vascular system of the host plant and green leaves that exhibit high transpiration rate (Ariga, 1996). The weed survives by maintaining an intensive uptake of water, carbohydrates and other nutrients from the host (Gurney *et al.*, 1995). The symptoms of *Striga* damage on the host plants include stunting growth, drought-like leaf wilting, chlorotic lesions and leaf rolling (Bagayoko *et al.*, 2000)

### 2.2.1 The biology of *Striga* species

*The Striga life cycle*

A good understanding of the population dynamics of *Striga* requires a closer look at its most important life cycle stages (Fig. 2.1).

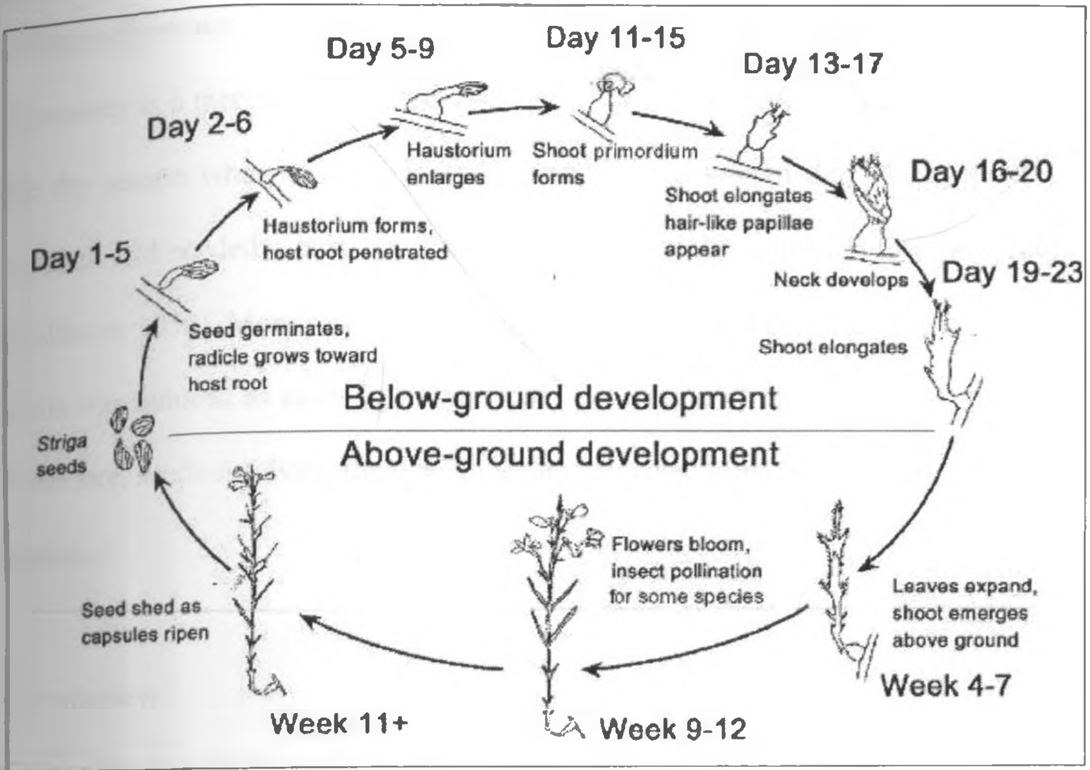


**Fig. 2.1:** General life cycle of *Striga* species

Source: Berner, *et al.*, 1997

*Seeds*

Seeds are the sole source of inocula for *Striga.* They are produced in abundance, roughly 10,000 to 100,000 or more per flower stalk (Gressel and Valverde, 2009). A flowering plant can bear from one to 30 flower stalks. Therefore, the number of seeds added to one square meter of soil each year could be in the millions. Seeds weigh 5 x $10^{-6}$ g each and are about 200 microns wide by 300 microns long (Berner *et al.*, 1997). Seeds have long life expectancies under both laboratory and field conditions (Samaké *et al.*, 2006) and a persistent seed bank can build up within one or two years of flowering *Striga* plants occurring in a field (Ransom, 2000).

*Primary dormancy*

Dormancy is a mechanism that prevents germination of seeds during unfavourable conditions in the dry season when the host is not present. It was known that freshly produced seeds were dormant and needed a post-ripening period of about six months before being able to germinate (Vallance, 1950). More recent research has challenged this point of view as germination of fresh seeds was induced as early as 28 days after pollination of the flowers (Aigbokhan *et al.*, 1998). Therefore, seeds surviving the dry season are expected to be non-dormant at the start of the rainy season.

*Germination*

Germination of *Striga* seeds is triggered by the presence of strigolactones, which are exuded by host roots (Rugutt *et al.*, 2002). When a host or a non-host root exudes trace amounts of germination stimulants, a chemical gradient is created. *Striga* seeds use this gradient to increase their chances of germinating only in the vicinity of potential host roots and to find the host root by growth of the radicle up the concentration gradient, in a process called chemotropism (Bouwmeester *et al.*, 2003). The germinated seed needs to find and attach itself to the host root within three to five days before seed reserves are depleted (Matusova *et al.*, 2005). Furthermore, the radicle is only able to grow to a maximum of 5 mm and so *Striga* seed should only germinate if the host root is 5 mm or less away (Ramaiah *et al.*, 1991). Seed exposure to moist conditions in combination with temperatures of between 25 and 45 °C for a minimum of four days makes seeds responsive to germination stimulants. This period is referred to as pre-conditioning (Kim and Adetimirin, 2001).

*Attachment and underground development*

Contact between the tip of the *Striga* radicle and the host root initiates an attachment process that leads to the formation of a root structure called the haustorium. The haustorium links the xylem sap flow of the host root with that of the parasite and connects the parenchyma tissues of the host and the parasite (Pageau *et al.*, 2003). This connection allows *Striga* to withdraw water, nutrients and carbon assimilates from the host (Pageau *et al.*, 1998). The attached seedling causes damage to its host in two ways. The first effect on host growth is the competition for water, nutrients, assimilates and amino acids between the host and the attached *Striga* seedling (Bewabi *et al* 1984). The second, pathogenic effect from the attached seedling is a disruption of the host's hormonal balance and a reduction of the host's photosynthetic process (Watling and Press, 2001). From the time of attachment until emergence, *Striga* is fully dependent on the host for water, nutrients and assimilates, making it a complete parasite during this stage of its life cycle (Fig.1).

*Emergence*

The time between attachment and emergence can vary from four to seven weeks (Fig. 1). Upon emergence, the leaves and stems turn green and start to photosynthesize. There is evidence for density dependent mechanisms that regulate the maximum number of plants that can emerge and survive to maturity per host (Van Delft, 1997). After pollination, a green capsule with seeds is formed within seven to ten days. Flowering is a continuous process, hence flower buds and capsules can be found simultaneously on one plant or flower stalk (Gbehounou *et al.*, 2003). Senescence sets in from the tip of the capsule downwards. Eventually, the capsule turns black and opens, shedding its seed (Van Mourik, 2007).

*Fecundity*

The number of seeds produced per mature *Striga* plant varies widely and may depend on the growing conditions, host species and host variety. Estimates of the average fecundity range from 5,000 to 100,000 seeds per flower stalk (Gressel and Velverde, 2009).

*Seed shed and dispersal*

The time between capsule formation and its opening when ripe is about one week (Fig. 1). Wind, runoff water, cattle, harvested plant material, agricultural implements and infested crop seed lots may vector the *Striga* seeds (Reda *et al.*, 2005). Wind, water and tillage are probably responsible for short distance dispersal within fields or between neighboring fields, whereas harvested plant material, infested crop seeds and grazing cattle may facilitate long distance dispersal between villages and regions (Berner *et al.*, 1997). Berner *et al.* (1994) found average densities of between 15 and 23 intact *Striga* seeds per 10 cattle droppings outside and inside infested fields in *Striga* infested areas, respectively. This would mean that on average, 1.5 *Striga* seeds are present in each cow dropping in uninfested fields within an infested region.

## 2.3 Effect of soil physical-chemical characteristics and fertilizers on *Striga* growth and development

Soil moisture and temperature affect *Striga* germination and development. Patil (2007) reported that soils that were occasionally flooded were free from *Striga* whereas better drained soils were heavily infested. A study by Mohamed *et al.* (1998) found that *Striga* seeds grown in soil with less than 10 percent moisture levels at the start of conditioning had germination greater than 90 percent. Soil moisture levels of over 10 percent resulted in 60 percent germination. Hence, high soil moisture is generally not favourable for the growth and development of *Striga* (Gbehounou *et al.*, 1996)

*Striga* is more problematic on low fertility soils. High soil nitrogen availability has been shown to suppress *Striga* germination and attachment (Pierce *et al.*, 2003). Application of organic amendments and mineral nitrogen (N) reduced the number of *Striga* plants (Kayeke *et al.*, 2007). Organic amendments that released moderate quantities of N seem to have increased the carrying capacity of the host to an extent that more *Striga* biomass was produced which led to higher seed bank replenishment (Kranz *et al.*, 1998). Hence, it is not the quantity but the rate of release of the nitrogen that is essential for positive effect on *Striga*. Ayongwa (2011) indicated that timing of inorganic N application is more important than the amount applied. Early fertilizer application even in small N quantities potentially reduces *Striga* infestation. Application of potassium promoted the stimulant activity in the host and led to increased *Striga* incidence while phosphorus did not have an effect on *Striga* seed germination and infestation (Raju *et al.*, 1990; Farina *et al.*, 1985).

However, from available literature *Striga* seed production and control measure has been related in few studies (Rodenberg *et al.*, 2006a; Van Mourik *et al.*, 2007). A study by Rodenberg *et al.* (2006), observed that most resistant varieties reduced *Striga* seed production by 70 to 93% compared with the most susceptible genotype. Van Mourik (2007) pointed out that the effects of fertilizers on *Striga* seed production are unknown. Fertiliser trials showed negative effects on *Striga* incidence and reduced crop damage particularly when high rates were used (Gacheru and Rao, 2001). However, there is a need to understand how nutrient status relates to *Striga* reproduction. A well fertilized sorghum plant induces fewer *Striga* seeds to germinate than a non fertilized plant (Gurney *et al.*, 1999; Van Ast, 2006). Fewer stimulated *Striga* seeds may also mean delayed attack of the host, low *Striga* emergence which may drastically reduce *Striga* seed production. Therefore, the current study would provide critical information through determining the various effects that both organic and inorganic fertilizers could have on *Striga* reproduction.

## 2.4 *Striga* management

Many researchers have suggested that an integrated *Striga* management (ISM) approach would be the best strategy for short and long-term *Striga* control and crop yield improvement (Kabambe *at al.*. 2007). However, the concept of ISM, like integrated pest management also implies that the choices of control options must be based on a sound knowledge of the biology and population dynamics of the pest (Ehler, 2006). The life cycles of the economically important *Striga* species are very closely linked to the growing seasons of their hosts (Bewabi *et al.*, 1991).

*Striga* species produce a massive amount of tiny dust-like seeds. At a density of 20 plants $m^{-2}$, a density which is commonly observed in farmers' fields, the number of seeds added to one square meter of soil each year could be in the millions (Van Mourik, 2007). Controlling the production of new *Striga* seeds is therefore an important component of a long-term control programme (van Ast *et al.*, 2005). Hand pulling of *Striga* has long been advocated for and is one option that can be implemented by most farm families. Nevertheless, hand pulling is not widely practiced in most of Africa probably because of the limited immediate return from the practice and the tediousness of the task (Parker, 2009). Ransom (2000) reported that S*triga* seed numbers in the soil declined by 48% over the four season period in hand weeded plots. However, when no hand weeding was implemented, seed numbers in the soil increased by 200% over the same period.

*Striga* seed banks can be reduced by inducing suicidal germination (Kayeke *at al*., 2007) with crop rotation, trap crops or through reducing *Striga* reproduction (Reda *et al*., 2005). Rotating susceptible cereal crops with crops that are not parasitized by *Striga* has long been advocated for as a simple way of avoiding crops losses. Furthermore, rotating with trap crops, that is, crops that induce the germination of *Striga* but are not themselves parasitized can also be used to reduce the level of *Striga* seeds in the soil (Oswald *et al*., 1999; Khan *et al*., 2007).

Researchers on long-term trials observed that the combination of relatively high rates of fresh organic matter and sufficient levels of nitrogen fertilizer resulted in only a slight increase in *Striga* seed numbers (Bationo *et al*., 2007). However, it is important to identify the optimum dose of organic and mineral N fertilizers required to maintain adequate nutrient supply for increased crop yields and reduced *Striga* reproduction.

*Striga* control methods such as resistant varieties, chemicals, biological control agents, catch cropping and seed-dressing require not only considerable resources in time, labor and monetary investments by farmers, but also a thorough training which are often not at hand in small-scale subsistence farming households (Oswald, 2005). Thus, they have had no major impact or acceptance among farmers. Furthermore, there are numerous strains of *S. hermonthica* and *S. asiatica* with different levels of virulence, so host-crops might show resistance in one region but succumb to *Striga* in another (Oswald *et al*., 2002). Hand-weeding seems to be a straightforward approach to interrupt the growth cycle of *Striga*, easy to practice and farmers are reluctant to employ it. One reason is that *Striga* emerges in most host-crops five to six weeks after planting and it takes another three weeks until the plants are big enough to be uprooted, which means at that time, it has already done considerable damage to the crop (Bewabi, 1981).

## 2.5 Effect of soil fertility management on sorghum growth and yield

Nitrogen and phosphorus among other nutrients are major yield determining factors for sorghum. Nitrogen availability in sufficient quantity throughout the growing season is essential for optimum crop growth (Kogbe and Adediran, 2003). An adequate supply of N is associated with vigorous vegetative growth and a dark green colour. An imbalance of N or an excess of this nutrient in relation to other nutrients, such as P, K, and S, can prolong the growing period and delay crop maturity (Marti and Mills, 1991). Phosphorus is the most important nutrient element (after nitrogen) limiting agricultural production in most regions of the world (Holford, 1997; Kogbe and Adediran, 2003). It is a structural component of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), the two genetic entities that are essential for the growth and reproduction of living organisms. This means that inadequate P supply will result in a decreased synthesis of RNA, the protein maker, leading to depressed growth (Hue, 1995). Phosphorus deficient plants are stunted with a limited root system and thin stems. The plants may produce only one small ear or panicle containing fewer and smaller seeds than usual. Grain yield is often severely reduced with phosphorus deficient (Jones *et al.*, 2003).

Organic manures are valuable sources of nutrients and the yield increasing effect of manure is well established (Agbede *et al*, 2008; Hassan *et al.*, 2006). Apart from the nutrients in manure, its effects on the improvement of soil organic matter, soil structure and the biological life of the soil are well recognized particularly at high rates of application (Ghosh *et al.*, 2004; Gworgwor and Weber, 1991). There is also some evidence that it may contain other growth-promoting substances like natural hormones and B vitamins (Leonard, 1986). Manure N and P are present in organic and inorganic forms. Plants take up nutrients in the inorganic form. Therefore the organic forms must be mineralized or converted into inorganic forms over time before they can be used by plants. The availability of K in manure is considered similar to that in commercial fertilizers since it is present mainly in the inorganic form (Motavalli *et al.*, 1989).

A study by Motavalli *et al.* (1989) has demonstrated that application of manure will produce crop yields equivalent or superior to those obtained with chemical fertilizers. Crop quality has also been improved by manure application (Eck *et al.*, 1990; Pimpini *et al.*, 1992). A field experiment conducted in northeastern Ethiopia revealed that combined application of farmyard manure and inorganic fertilizers increased dry-matter production by 147% to 390% and grain yield by 14% to 36% (Bayu *et al.*, 2006). Muchow (1988) found that the increase in sorghum harvest index, nitrogen harvest index, and grain size during grain-filling were essentially linear and the rates were constant under variable N supply. The author concluded that nitrogen supply had a greater effect on the effective duration of grain-filling in sorghum.

### 2.6 Descriptions of study areas

The study was carried out in semiarid areas of Dodoma and Morogoro regions of Tanzania, where *Striga* infested fields are found. Dodoma Region has a semi arid type of climate, which is characterized by a long dry season lasting between May and early December. In the long dry season, persistent desiccating winds and low humidity contribute to high evapo-transpiration and to soil erosion. The average rainfall for Dodoma ranges from 570 to 700 mm, and about 85 percent of this falls in the months of December and April (Mbwaga *et al.* 2000). Apart from the rainfall being relatively low, it is rather unpredictable in frequency and amount. Temperatures in the region vary according to altitude but generally the average maximum and minimum temperatures are 31°C and 18°C respectively. In June - August, temperatures are at times very high with hot afternoons up to 35°C and chilly nights on hilly areas down to 10°C (URT, 2002). The characteristic vegetation of the region is of "bush" or thicket type, which is widespread throughout the area. Depressions and seasonally wet areas with impeded drainage support grasses and sometimes a mixture of grasses with woody plants. Wherever the natural vegetation has been altered by agricultural activities, regenerating bushes mixed with annual herbs and grasses have formed a type of induced vegetation (URT, 2002).

In Morogoro, the study area is located in the north-western part, Mvomelo district. The climate of the area can generally be described as a sub-humid tropical type. The mean annual rainfall of the area varies from about 750 mm (Melela) to about 1050 mm (Pangawe) (Msanya *et al.*, 2003). Most areas in the district experience bimodal rainfall pattern characterized by two rainfall peaks in a year with a definite dry season separating the short and long rains. The short rain season is from October to December while the long rain season starts in March and ends in May. The onset of both rains and their distribution are irregular and unreliable (Kaaya *et al.*, 1994). The mean annual air temperature for most places in the district is about 24°C. The soil is a very deep black mbuga soil with a firm consistence and predominantly sandy clay topsoil. Vegetation in most areas of the district is wetland dominated by grass-like vegetation (Msanya *et al.*, 2003). Figure 2.2 represents a map showing the study areas.

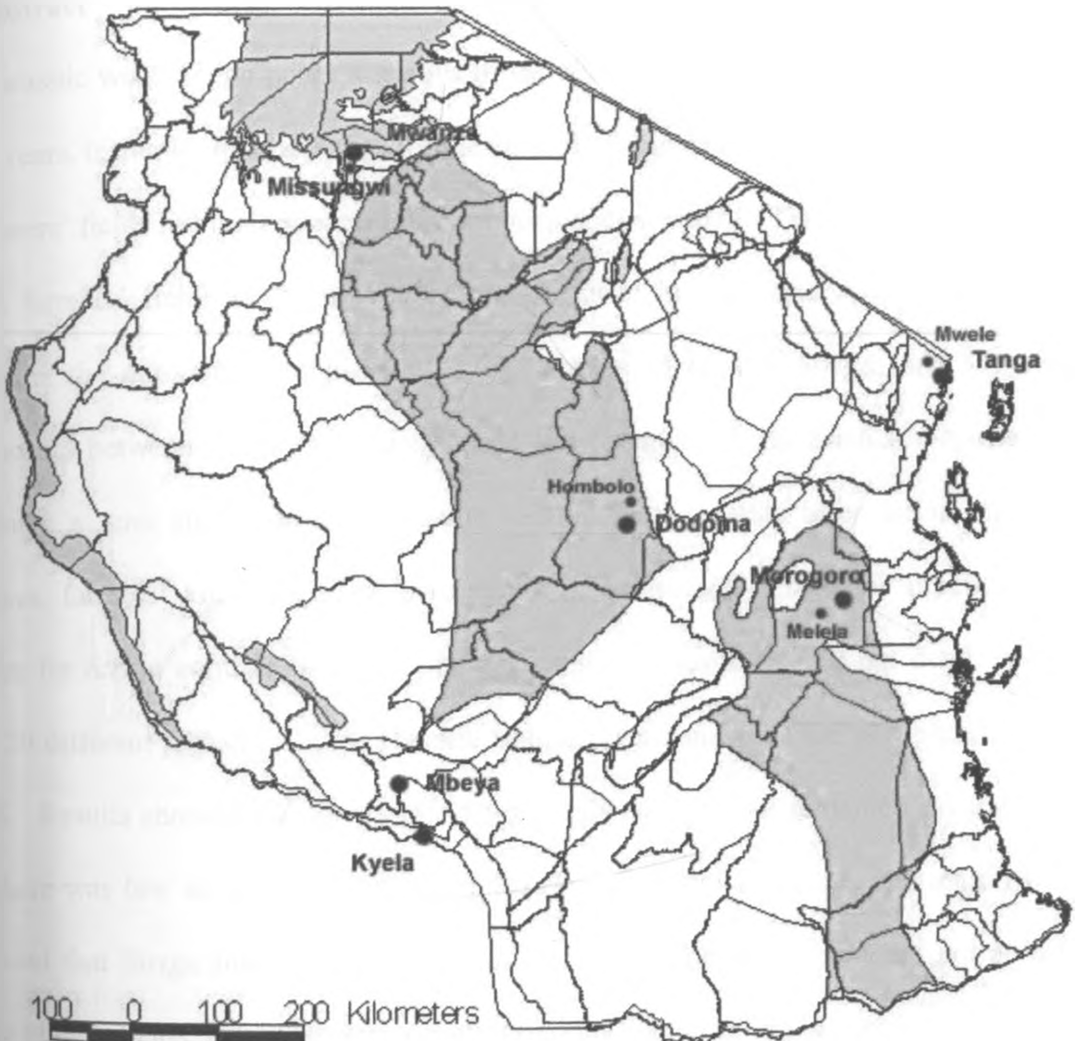


**Fig. 2.2:** Location map of the study areas (semi-arid areas of Tanzania)

Source: Riches, C. 2003

# CHAPTER 3

# AGRONOMIC PRACTICES FOR STRIGA CONTROL AND EFFECT OF SOIL CHEMICAL CHARACTERISTICS ON *STRIGA* REPRODUCTION


## 3.1 Abstract

The parasitic weed *Striga* poses a serious threat to cereal production in sub-Saharan Africa. For many years, technological packages for the control of this weed were proposed and implemented on farmers' fields but their adoption has not been documented in Tanzania. A survey was carried out in farmers' fields in 2010/2011 cropping season in semi-arid areas of Tanzania to: (a) determine the agronomic practices used by farmers to control *Striga*; and (b) evaluate the relationship between *Striga* reproduction and soil chemical characteristics. For the first part of the study, a semi structured questionnaire was used to generate information on the cropping practices, farmers' knowledge and perceptions of *Striga* and agronomic practices adopted by farmers for *Striga* control. In the second part, soil samples at 0 – 20 cm depth were collected from 20 different farmers' fields. The soil samples were analyzed for pH, organic carbon, N, P and K. Results showed that *Striga* infestation in the study areas remained invariably very high and there was low adoption of recommended *Striga* control methods. The majority of farmers indicated that *Striga* infestation in the area was increasing and they were not able to control *Striga* in their fields. Amongst *Striga* control options, hand-pulling, deep tillage and crop rotation were mentioned by the farmers during the surveys. Two species of *Striga* namely *Striga asiatica* and *Striga forbesii* were observed, although *Striga asiatica* was the dominant species. Regression analysis of agronomic practices and soil chemical characteristics revealed a positive improvement of soil N and organic carbon and reduction of soil P and K content as one shifted from sole planting to intercropping. The results showed that potassium was highly positively

related to the number of capsules/*Striga* plant. There was a reduction in the number of capsules/plant as one moved from sole planting to intercropping. Based on these findings, many years of emphasis on *Striga* research and extension have not resulted in effective management of the *Striga* problem. Potassium content in the *Striga* infested soils positively influenced *Striga* reproduction and seed bank replenishment.

## 3.2 Introduction

Soil fertility is a major constraint to cereal production in Africa (Ransom, 2000; Schlecht *et al*., 2006). Apart from the direct negative effects of low soil fertility on agricultural production and food security, low soil fertility increases susceptibility of the crop to biotic pests. A major biotic pest in Africa is the parasitic plant of the genus *Striga* (Scrophulariaceae). Most important species of genus are *Striga asiatica, S. hermonthica* and *Striga forbesii* which are mainly found on cereals such as maize, sorghum, pearl millet and rice (Mbwaga *et al*., 2007).

An important factor in the *Striga* life cycle is the production of large numbers of minuscule seeds that cause rapid increase in parasite population density once the first infestation has occurred (Horton, 1990). The seeds remain dormant until they are chemically triggered by the host plant to germinate (Kwacha, 2001). The large number of parasitic seeds produced increases the chances that some *Striga* seeds will find a suitable host. Every year some seeds germinate, some revert to dormancy while others are added from the new growth, continually enriching the seed reserve in the soil (Ejeta *et al*., 2000).

For many years, technological packages were proposed and implemented on farmers' fields by researchers from different research programs and *Striga* control projects (MacOpiyo *et al.*, 2010). Components of the package included hand-pulling of mature *Striga* plants, killing adult plants before flowering by application of herbicides, application of nitrogen fertilizer, using trap crops as intercrops or in rotation with crops that are non hosts to *Striga* and sowing *Striga* resistant crop varieties. Whether farmers have adopted these technological packages in Tanzania has not been established.

It has been reported that soil characteristics play a role in *Striga* infestation. In heavy soils, low temperatures caused low *Striga* seed germination while light soils had higher temperatures and resulted in higher *Striga* seed germination (Parker and Riches, 1993). On the other hand, light soils are prone to nutrient leaching, resulting in high *Striga* infestation due to low levels of soil nitrogen (Mohamed, 2004). A study by Sauerborn (1991) showed that germination of *Striga* occurred between 0 and -1.29 MPa. This means that *Striga* germination takes place when the soil is wet enough. Another study found that *Striga* germination was higher at 0 MPa water potential and temperature range of $25^0$C to $35^0$C. It was concluded that water stress during germination reduced *Striga* growth and development (Mohamed, 2004). Generally, high moisture levels in the soil are unfavourable for germination and development of *Striga* (Ayongwa, 2001).

Raju *et al.* (1990) and Farina *et al.* (1985) observed that application of potassium in the absence of N promoted the stimulant activity in the host and led to increased *Striga* incidence while the presence or absence of phosphorus did not have an effect on *Striga* seed germination and infestation. Okonkwo (1991) observed that under alkaline conditions germination of *Striga* was inhibited because the germination stimulant was inactive. All these studies did not provide any insight on the influence of these nutrients on *Striga* seed production and consequently *Striga* infestation. Therefore, the current study was undertaken to identify agronomic practices adopted by farmers in *Striga* control and the relationship between soil physical-chemical characteristics and *Striga* reproduction.

## 3.3 Materials and methods

### 3.3.1 Field sites

A survey was carried out in farmers' fields in 2010/2011 cropping season at Melela and Mbande villages in Morogoro and Dodoma regions respectively. In Morogoro, the study area was located at Mvomelo district in the north-western part of Morogoro. The climate in Mvomelo district can generally be described as a sub-humid tropical type. The mean annual rainfall of the district varies from about 750 mm (Melela) to about 1050 mm (Pangawe) (Msanya *et al.*, 2003). Most areas in the district experience bimodal rainfall pattern characterized by two rainfall peaks in a year with a definite dry season separating the short and long rains. The short rain season is from October to December while the long rain season starts from March and ends in May. The onset of both rains and their distribution are irregular and unreliable (Kaaya *et al.,* 1994). The mean annual air temperature for most places in the district is about 24°C. The soil is a very deep black mbuga soil with a firm consistence and predominantly sandy clay topsoil (Msanya *et al.*, 2003).

In Dodoma, the study was conducted at Mbande which is situated in Kongwa district. Kongwa district is characterized by a long dry season occurring between late April and early December. The average rainfall ranges from 570 to 700 mm and about 85 percent of it falls between

December and April (Mbwaga and Ruches, 2000). Apart from the rainfall being relatively low, it is rather unpredictable in frequency and amount. Generally, the average maximum temperature in the area is 31°C. The predominant soil type of the area can be described as thin stony soils with predominantly sand or sandy clay (URT, 2002).

### 3.3.2 Surveys and data collection

*Preparation of questionnaire*

A semi-structured questionnaire taking into account the objectives was constructed before setting out to the field. The questionnaire contained dichotomous and open-ended questions to capture necessary diverse issues under investigation. Each question was made simple and phrased in a manner that would imply the same meaning to all respondents. That is, questions that would carry more than one meaning were avoided (Nyariki, 2009). Leading questions were avoided as they usually suggest the answer the interviewer wants to hear, and the respondent may agree with the interviewer simply because that is the expected response (sample of questionnaire in the appendix 1).

Many questions were constructed in a way that allowed adequate room to make considered choices, so as to avoid forcing answers. The possibility for no response was born in mind. An effort was made to make the questionnaire as short as possible, including only the questions pertinent to the objectives of the study to avoid people becoming bored after answering an unending list of questions, which may also lead to incorrect answers (Nyariki, 1997). The questionnaire covered general farmland characteristics, the cropping practices, farmers' knowledge and perceptions of the *Striga* and agronomic practices adopted by farmers for *Striga* control.

*Pre-testing of questionnaire*

The questionnaire was pre-tested with 10 farmers before it was used in the main study. The 10 farmers were selected from the study area but did not come from the main sample. The main reasons for pre-testing were to ensure that the final questionnaire had only relevant and appropriately phrased questions to be put to the respondent. During the pre-testing exercise, informal gatherings were held to question them about mentioned operations.

*Sampling procedure*

Identification and training of enumerators (extension officers) from the local community was carried out before the actual fieldwork was undertaken. This was necessary to speed up the process of data collection. The enumerators were trained for two days to ensure that they did not deviate from the required protocol, thereby reducing bias in the sample data collected.

Stratified random sampling procedure was used to collect the data. The goal of stratified sampling was to achieve desired representation from the different subgroups in the population (Mugenda and Mugenda, 1999). The method involves dividing the population into two subpopulations using given criteria, and then a simple random sample is taken from each subpopulation. The study area was divided into two strata based on regions, namely, Mbande-Dodoma and Melela-Morogoro. The two strata were considered to have distinct agricultural practices and climatic conditions.

*Actual study*

This study was conducted between the months of January and May, 2011. A baseline survey was carried out in January, 2011 to identify the target sample size. The final sample size of 60 households was systematically selected, 30 from Mbande-Dodoma and 30 from Melela-Morogoro. This was done by taking into account the statistical requirement to have a minimum size of 30 (Nyariki, 2009), the possibility of non-response and limited financial outlays and time. Further, the terrain in the study area is difficult and the infrastructure is poor. Taking all these factors together, larger samples would have reduced the resources and as a result the quality of data collected would have suffered.

*Striga intensity*

In each site a total of 10 farmers were randomly selected using stratified sampling technique and their fields were visited. Field visits were done with farmers to collectively assess the *Striga* situation and cross check respondents' interview answers with field observations. The extent and intensity of *Striga* infestation was assessed as described by MacOpiyo *et al.* (2010). *Striga* intensity was defined in five categories ranging from low to severe. Each category was assigned a specific range of *Striga* plant density. Low infestation was defined as having between 1 and 4 *Striga* plants per $m^2$, medium had between 4 and 9 plants per $m^2$, and severe infestation had more than 9 *Striga* plants per $m^2$.

Emerged *Striga* plants were counted from each field as described by Kim (1994). In infested fields, a quadrant of 1 $m^2$ was randomly thrown three times and the number of emerged *Striga* plants was physically counted to determine the above ground *Striga* incidence. *Striga* reproduction was determined by sampling 10 mature but unopened, green seed capsules from five randomly selected *Striga* plants in each field (average of two seed capsules/plant). These seed capsules were air dried and weighed. The total weight was adjusted by 10% as a correction factor for unremovable trash. The average weight per capsule was divided by 5 x $10^{-6}$ (average *Striga* seed weight, Berner *et al.* 1997) to get an estimate of the seed production per capsule. The number of capsules per plant was counted for estimation of fecundity (seed production per plant).

*Soil analysis*

Soil samples were collected from different fields at 0 – 20 cm depth, taken to the soil laboratory and analyzed for physical (soil moisture) and chemical components (Organic carbon, N, P, K and pH). The fresh weight of the soil and the weight of oven dried soil were recorded. Then soil moisture content was estimated as follows:

$$PW\ (\%) = \frac{WS1 - WS2}{WS2} \times 100$$

Where PW = moisture percentage of dry weight basis

WS1 = weight of fresh wet soil (g)

WS2 = weight of oven dried soil (g)

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory procedures (Bremner and Mulvaney, 1982). Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982) and soil pH was measured in a 1:1 soil-water ratio using a glass electrode pH meter. Available P was determined by the Bray 1 method (Bray and Kurtz, 1945). Exchangeable bases $K^+$ displaced by ammonium acetate extracts were determined by atomic adsorption spectrophotometer (Thomas, 1982).

### 3.3.3 Data analyses

The questionnaires for the field surveys and observations were manually coded and analyzed using the Statistical Package for Social Sciences (SPSS version 15). Percentages were used to identify the agronomic practices adopted by farmers, change overtime in *Striga* infestation levels and cropping systems. The xlSTATA software was used for regression analysis between *Striga* counts, number of capsules and soil properties. Principal component analysis was performed on soil properties before a regression, to limit the number of variables to be measured afterwards. The regression analysis between agronomic practices, soil characteristics and number of capsules was done using SPSS.

An Ordinary Least Squares (OLS) regression technique was used to determine the relationship between agronomic practices, soil chemical characteristics and the number of capsules/plant. In order to eliminate multicollinearity, a correlation analysis was conducted to identify variables, which were significantly correlated (correlation coefficient, $r \geq 0.5$) prior to performing a multiple linear regression. Pairs of variables with highly significant correlation coefficients were scrutinized and either of them dropped depending on their influence (t-value) on the regress. Variables with higher t-values (more influence on the dependent variable) were retained for the Ordinary Least Squares (OLS) regressions. A general equation for a multiple linear regression

(OLS) given $k$ variables (a regress and and ($k$-1) regressors) is as specified below (Gujarat, 2003):

$$Y_i = \beta_1 + \beta_2 X_{1i} + \beta_3 X_{2i} + \ldots + \beta_k X_{ki} + \mu_i$$

Where $Y$ is the dependent variable, $X_1, \ldots, X_k$ is a set of explanatory variables, $i$ denotes $i^{th}$ variable, $\mu$ is the error or disturbance term associated with the model, and $\beta_1, \ldots, \beta_k$ are coefficients representing parameters estimators of the variables in the model.

A series of multiple regressions were conducted using agronomic practices, number of capsules/plant and soil chemical characteristics as the regress until the best fit of the model were attained. The criteria for determining the variables that best defined the estimated model (goodness of fit) was based on the coefficient of determination ($R^2$); adjusted $R^2$, F statistic, significance of explanatory variable (t-value), the sign or direction of influence of the independent variables, and the number of significant explanatory variables in the model.

## 3.4 RESULTS

### 3.4.1 Farmers' constraints

Each farmer named at least three of the most important constraints to sorghum production (Table 3.1). *Striga* infestation (36.7% at Mbande, 40% at Melela) and low rainfall (30% at Mbande and 43.3% at Melela) were the major constraints cited at both locations. None of the farmers cited disease (smut) as a major constraint to sorghum production at Melela while 6.7% cited disease as a major constraint to sorghum production at Mbande (Table 3.1).

**Table 3.1:** Importance of production constraints as a percentage (% respondents) of all constraints mentioned during the study

| Constraint | Mbande (n = 30) | Melela (n = 30) | Mean |
|---|---|---|---|
| *Striga* | 36.7 | 40.0 | 38.3 |
| Rainfall | 30.0 | 43.3 | 36.7 |
| Birds | 26.6 | 16.7 | 21.7 |
| Diseases (smut) | 6.7 | 0 | 3.3 |
| Total | 100 | 100 | 100 |

The majority of farmers at both Mbande (90%) and Melela (93.3%) indicated that *Striga* infestation in the area was increasing while few farmers at Mbande (10%) and Melela (3.3%) thought it was decreasing (Table 3.2 and 3.3). The majority of farmers in both at Mbande (56.7%) and Melela (26.7%) perceived an increase in *Striga* due to the ability of *Striga* to produce many seeds. At Mbande and Melela, 10% and 23.3% of farmers, respectively, held that lack of control measures was responsible for the worsening *Striga* situation. Low rainfall and decline in soil fertility were also mentioned as the underlying causes (Table 3.2 and 3.3).

**Table 3.2:** Farmers' perception (% respondents) of changes in the *Striga* situation over time

| Trend | Mbande | Melela | Mean |
|---|---|---|---|
| Increasing | 90 | 93.3 | 91.7 |
| Decreasing | 10 | 3.3 | 6.7 |
| No change | 0.0 | 3.4 | 1.6 |
| Total | 100 | 100 | 100 |

**Table 3.3:** Farmers' causal explanation for observed *Striga* dynamics (% respondents)

| Reason | Mbande | Melela | Mean |
|---|---|---|---|
| No control measures | 10.0 | 23.3 | 16.7 |
| Soil infertility | 16.7 | 13.4 | 15.0 |
| Low rainfall | 0.0 | 23.3 | 11.7 |
| Continuous cropping | 10 | 3.3 | 6.7 |
| *Striga* seed production | 56.7 | 26.7 | 41.6 |
| I don't know | 6.6 | 10 | 8.3 |
| Total | 100 | 100 | 100 |

At Mbande and Melela, 53.3% and 46.7% of the farmers' mentioned that they saw *Striga* for the first time in their fields during the last five years, respectively (Table 3.4). Other farmers at Mbande (13.4%) and Melela (23.3%) mentioned that they saw *Striga* in their fields more than 20 years ago.

**Table 3.4:** The first time *Striga* was seen on farmers' fields (% respondents)

| Time | Mbande | Melela | Mean |
|---|---|---|---|
| 1 - 5 years | 53.3 | 46.7 | 50.0 |
| 6 - 10 years | 33.3 | 30.0 | 31.7 |
| >20 years | 13.4 | 23.3 | 18.3 |
| Total | 100 | 100 | 100 |

The majority of the farmers at Mbande (73.3%) and Melela (78.6%) said they were not using any method to control *Striga* in their fields (Table 3.5). Amongst *Striga* control options, hand-pulling, deep tillage and crop rotation were mentioned by the farmers during the surveys.

The majority of farmers at Mbande (38.8%) and Melela (36.6%) reported that sorghum seed was the main avenue for *Striga* spread from one field to another (Table 3.6). Farmers mentioned wind, animals and run-off as the other means by which *Striga* spread from one field to another.

**Table 3.5:** Control measures used by farmers (% respondents)

| Control | Mbande | Melela | Mean |
|---|---|---|---|
| Crop rotation | 10.0 | 3.6 | 6.9 |
| Hand-pulling | 10.0 | 7.1 | 8.6 |
| Deep tillage | 6.7 | 10.7 | 8.6 |
| None | 73.3 | 78.6 | 75.9 |
| Total | 100 | 100 | 100 |

**Table 3.6:** How *Striga* is spread in farmers' fields (% respondents)

| Way | Mbande | Melela | Mean |
|---|---|---|---|
| Wind | 18.4 | 18.4 | 18.3 |
| Animals | 16.3 | 22.4 | 19.3 |
| Run-off | 16.3 | 8.2 | 12.3 |
| Seed | 38.8 | 36.7 | 37.8 |
| I don't know | 10.2 | 14.3 | 12.3 |
| Total | 100 | 100 | 100 |

### 3.4.2 *Striga* species identified

The dominant *Striga* species observed in the cereal based fields across the two locations was *Striga asiatica* (L.) Kuntze. The species is an erect herb reaching a height of 15 to 30 cm, with bright to brick red flowers, calyx directly ten ribbed, corolla tube 6 to 9 mm in width. Flowers are self-pollinated (Plate 3.1). Two fields at Melela were found infested with *Striga forbesii* (Plate 3.2). *Striga forbesii* is an erect, simple or little branched herb growing to height of about 0.5 m, flowers are pink, scarlet or yellow, 10 – 20 mm diameter. The corolla tube is 20 – 25 mm long and sparsely pubes-cent. It can be distinguished from other species by its characteristics of having only two open flowers on each inflorescence, salmon-pink colored corolla and lobed leaves (Ramaiah *et al.* 1983)

**Plate 3.1:** Sorghum field infested with *Striga asiatica* at Mbande

**Plate 3.2:** Sorghum field infested with *Striga forbesii* at Melela

### 3.4.3 Fertilizer use, cropping system and yield in sorghum based fields

Majority of farmers at Mbande (86.7%) and all farmers at Melela were not using fertilizers. Sole planting of sorghum was practiced by 73.3% and 76.7% of the farmers at Mbande and Melela respectively (Table 3.7 and 3.8).

**Table 3.7:** Fertilizer inputs used (% respondents)

| Input | Mbande | Melela | Mean |
|---|---|---|---|
| None | 86.7 | 100 | 93.3 |
| Farmyard manure | 13.3 | 0 | 6.7 |
| Total | 100 | 100 | 100 |

**Table 3.8:** Cropping system practiced (% respondents)

| System | Mbande | Melela | Mean |
|---|---|---|---|
| Intercropping | 26.7 | 23.3 | 25 |
| Sole planting | 73.3 | 76.7 | 75 |
| Total | 100 | 100 | 100 |

### 3.4.4 Grain yield of sorghum

Grain yield/acre was slightly higher at Mbande as most farmers (46.7%) reported to harvest 5 to 6 bags of 100 kg each per acre while most farmers (46.7%) reported to harvest 3 – 4 bags at Melela. Generally, in both locations the yields were low as most farmers harvested 3 to 4 bags of 100 kg each per acre (Table 3.9)

**Table 3.9:** Grain yield of sorghum per acre (% respondents)

| Yield | Mbande | Melela | Mean |
|---|---|---|---|
| 3 – 4 bags | 43.3 | 46.7 | 45.0 |
| 5 – 6 bags | 46.7 | 40.0 | 43.3 |
| 7 – 8 bags | 10.0 | 13.3 | 11.7 |
| Total | 100 | 100 | 100 |

### 3.4.5 *Striga* plant counts/m², infestation level, number of capsules/plant and fecundity (seeds/plant)

Seventy five percent (75%) of the fields were severely infested while 25% were moderately affected (Table 3.10). None of the fields had low infestation (< 4 plants/m²). The *Striga* plant counts/m² ranged from 4.12 to 53.42. The number of capsules/plant ranged from 28 to 156.9 while fecundity ranged from 14028 to 78606.9 seeds/plant.

**Table 3.10**: *Striga* counts/m², level of infestation, capsules/plant and fecundity (seeds/plants)

| Site | *Striga* counts | Level of infestation (LI) | Capsules/plant | Fecundity (seeds/plants) |
|---|---|---|---|---|
| Mbande ≠1 | 5.25 | Medium | 52.0 | 35464.0 |
| ≠ 2 | 4.12 | Medium | 67.0 | 33634.0 |
| ≠ 3 | 5.00 | Medium | 45.7 | 21753.2 |
| ≠ 4 | 15.51 | Severe | 86.0 | 47386.0 |
| ≠ 5 | 7.15 | Medium | 28.0 | 14028.0 |
| ≠ 6 | 5.87 | Medium | 53.0 | 36146.0 |
| ≠ 7 | 11.67 | Severe | 60.2 | 30220.4 |
| ≠ 8 | 33.75 | Severe | 114.0 | 54264.0 |
| ≠ 9 | 22.33 | Severe | 123.4 | 67993.4 |
| ≠ 10 | 32.75 | Severe | 44.3 | 22194.3 |
| Melela ≠ 1 | 29.11 | Severe | 156.9 | 78606.9 |
| ≠ 2 | 19.33 | Severe | 87.5 | 48212.5 |
| ≠ 3 | 53.42 | Severe | 89.6 | 42649.6 |
| ≠ 4 | 24.75 | Severe | 123.4 | 61946.8 |
| ≠ 5 | 21.17 | Severe | 45.0 | 30690.0 |
| ≠ 6 | 23.08 | Severe | 65.0 | 32630.0 |
| ≠ 7 | 10.58 | Severe | 51.7 | 28486.7 |
| ≠ 8 | 21.00 | Severe | 58.0 | 29058.0 |
| ≠ 9 | 28.00 | Severe | 135.2 | 67735.2 |
| ≠ 10 | 15.48 | Severe | 78.3 | 37270.8 |
| LSD (≤ 0.05) | NS | - | NS | NS |

≠ represent site; NS = mean values not significant different; medium = 4 to 9 plants/m²; severe = > 9 plants/m²

The mean values for number of *Striga* plant counts, capsules/plant and fecundity were not significantly different between the two sites (Table 3.11). The mean number of *Striga* plants per

$m^2$ ranged from 14.30 (Mbande) and 24.6 (Melela) while the number of capsules/plant ranged from 67.40 (Mbande) to 89.10 (Melela). The fecundity values were 36308 and 45729 seeds/plant at Mbande and Melela, respectively.

**Table 3.11:** Mean values of *Striga* plant counts/$m^2$, number of capsules/plant and fecundity (seeds/plant)

| Site | *Striga* counts/$m^2$ | Number of capsules/plant | Fecundity (seeds/plant) |
|---|---|---|---|
| Mbande | 14.30 | 67.40 | 36308 |
| Melela | 24.60 | 89.10 | 45729 |
| Mean | 19.50 | 78.20 | 41018 |
| LSD | NS | NS | NS |

*NS = mean values not significant different

### 3.4.6 Soil chemical characteristics and agronomic practices in the 20 sampled fields at Mbande and Melela

The soil pH ranged from 5.32 to 6.65, but there were no significant differences among the sites in this parameter (Table 3.12). The level of organic carbon ranged from 0.45 to 0.78%. The values for total nitrogen ranged from 0.03 to 0.11%. Available P was significantly different ($P \leq 0.05$) among the fields. Phosphorus content ranged from 2.0 (Mbande) to 23.58 mg/kg (Melela). Exchangeable K ranged from 0.50 (Mbande) to 1.59 mg/kg (Melela) but there were no significant differences among the farmers' fields. Soil moisture was significantly different between farmers' fields and ranged from 7.47 to 14.70%. The majority of the sorghum fields sampled were sole cropped with local varieties and not fertilized (Table 3.12).

*Table 3.12: Soil chemical characteristics and agronomic practices in the sampled fields at Mbande and Melela*

| | Nutrient composition | | | | | | Agronomic Practices | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | N (%) | OC (%) | P (mg/kg) | K (mg/kg) | pH | Moisture (V %) | Cropping Systems | Inputs used | Variety grown |
| Mbande ≠1 | 0.04 | 0.51 | 9.61 | 0.50 | 5.64 | 14.08 | Sole | None | local |
| ≠ 2 | 0.06 | 0.74 | 2.00 | 0.79 | 5.89 | 10.55 | Intercrop/cowpea | None | local |
| ≠ 3 | 0.11 | 0.60 | 14.76 | 1.35 | 6.61 | 11.19 | Sole | FYM | local |
| ≠ 4 | 0.08 | 0.78 | 13.00 | 1.59 | 6.65 | 10.06 | Sole | FYM | local |
| ≠ 5 | 0.07 | 0.65 | 3.50 | 0.59 | 5.57 | 12.22 | Intercrop/gnut | None | local |
| ≠ 6 | 0.05 | 0.54 | 2.71 | 0.64 | 5.4 | 10.11 | Sole | None | Macia |
| ≠ 7 | 0.04 | 0.49 | 3.55 | 0.57 | 5.32 | 11.79 | Sole | None | local |
| ≠ 8 | 0.07 | 0.55 | 4.00 | 0.83 | 6.34 | 11.66 | Sole | None | local |
| ≠ 9 | 0.05 | 0.58 | 5.43 | 0.91 | 5.97 | 10.94 | Sole | None | local |
| ≠ 10 | 0.03 | 0.45 | 7.55 | 0.77 | 6.2 | 7.47 | Sole | None | local |
| Melela ≠ 1 | 0.06 | 0.57 | 5.50 | 1.26 | 6.56 | 13.82 | Sole | None | local |
| ≠ 2 | 0.07 | 0.48 | 4.65 | 1.00 | 6.20 | 11.32 | Sole | None | local |
| ≠ 3 | 0.08 | 0.67 | 23.52 | 0.90 | 6.55 | 13.25 | Sole | None | local |
| ≠ 4 | 0.09 | 0.76 | 21.41 | 1.49 | 6.05 | 12.99 | Sole | None | local |
| ≠ 5 | 0.10 | 0.64 | 20.17 | 0.63 | 5.69 | 11.59 | Intercrop/cowpea | None | local |
| ≠ 6 | 0.09 | 0.66 | 12.83 | 0.66 | 5.57 | 13.20 | Sole | None | local |
| ≠ 7 | 0.11 | 0.60 | 9.87 | 1.50 | 6.56 | 9.94 | Intercrop/cowpea | None | local |
| ≠ 8 | 0.09 | 0.45 | 19.39 | 0.79 | 5.79 | 14.70 | Sole | None | local |
| ≠ 9 | 0.09 | 0.69 | 18.58 | 1.59 | 6.04 | 11.64 | Sole | None | local |
| ≠ 10 | 0.08 | 0.57 | 23.58 | 0.89 | 6.36 | 10.84 | Sole | None | local |
| LSD ($P \leq 0.05$) | 0.02 | NS | 4.69 | NS | NS | 1.32 | - | - | - |

≠ represent site; gnut = groundnuts; NS = mean values not significant different

### 3.4.7 Soil physical-chemical properties

The soil pH, %OC and K content were not significantly ($P \leq 0.05$) different across the study areas (Table 3.13). The means for soil moisture, nitrogen and phosphorus were significantly higher at Melela than at Mbande (Table 3.13).

**Table 3.13:** Mean values of soil physical-chemical properties of the study sites

| | | | | Nutrient compositions | | |
|---|---|---|---|---|---|---|
| | pH | MC (%) | OC (%) | N (%) | P (mg/kg) | K (mg/kg) |
| Mbande | 5.96 | 11.01 | 0.59 | 0.06 | 6.60 | 0.85 |
| Melela | 6.14 | 12.33 | 0.61 | 0.09 | 16.00 | 1.07 |
| Mean | 6.05 | 11.67 | 0.60 | 0.07 | 11.30 | 0.96 |
| LSD ($P \leq 0.05$) | NS | 1.33 | NS | 0.02 | 4.69 | NS |

*MC = moisture content; OC = organic carbon; NS = mean values not significant different

### 3.4.8 Interaction effect of agronomic practices on soil chemical properties and number of capsules/plant

The regression analysis of agronomic practices on soil chemical properties and *Striga* reproduction across the study areas is presented in Table 3.14.

**Table 3.14**: Interaction effect of cropping systems on soil chemical characteristics and *Striga* reproduction across the study areas

| Soil chemical characteristics | | $R^2$ | *Striga* reproduction | | $R^2$ |
|---|---|---|---|---|---|
| Explanatory term | Estimates | | Explanatory term | Estimates | |
| Cropping system | | | Constant | -109.49** | |
| Constant | 0.191 NS | | Cropping system | -36.181* | 0.43 |
| N (%) | 12.155* | 0.67 | Inputs used | 56.715* | |
| OC (%) | 1.679** | | | | |
| P (mg/kg) | -0.029* | | | | |
| K (mg/kg) | -0.574* | | | | |

*Regression is significant at the $p \leq 0.05$ level; **Regression is significant at the $p \leq 0.1$ level
OC = organic carbon

Regression analysis of agronomic practices and soil chemical characteristics revealed a positive and significant improvement of soil N and OC as one shifted from sole planting to intercropping (Table 3.14). There was negative and significant effect on P and K as one moved from sole planting to intercropping. Similarly, there was negative and significant effect on the number of capsules/plant as one moved from sole planting to intercropping and positive effect as one shifted from intercropping to sole planting (Table 3.14).

### 3.4.9 Interaction effect of soil chemical characteristics on *Striga* counts and capsules/plants

Principal component analysis on *Striga* counts and capsules/plant led to selection of total nitrogen, phosphorus and potassium that contribute much of the commulative variability of *Striga* counts and number of capsules/plant (Fig 3.1) since the remaining variables were positevely correlated with the selected variables (Table 3.15).

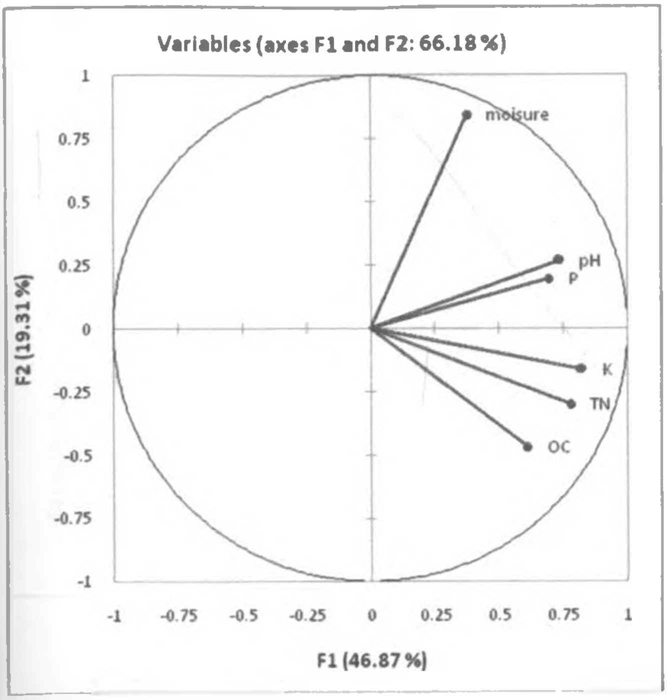


**Fig 3.1:** Discriminate analysis ordination graph showing contribution of soil chemical characteristics to *Striga* counts and number of capsules/plant

**Table 3.15:** Pearson correlation matrix

| Variables | TN | OC | P | K | pH | Moisture |
|---|---|---|---|---|---|---|
| TN | **1** | 0.439 | **0.609** | **0.529** | 0.374 | 0.029 |
| OC | | **1** | 0.292 | **0.481** | 0.211 | 0.026 |
| P | | | **1** | 0.309 | 0.278 | 0.386 |
| K | | | | **1** | **0.708** | 0.129 |
| pH | | | | | **1** | 0.372 |
| Moisture | | | | | | **1** |

*Values in bold are different from 0 with a significance level alpha ≤ 0.05*
*TN = total nitrogen; OC = organic carbon

The regression analysis showed that the interactions of phosphorus x potassium and phosphorus x nitrogen x potassium interaction contributed significantly ($P \leq 0.05$) to the explanation of variation in *Striga* counts as explained by their high standardized coefficients (Fig. 3.2).

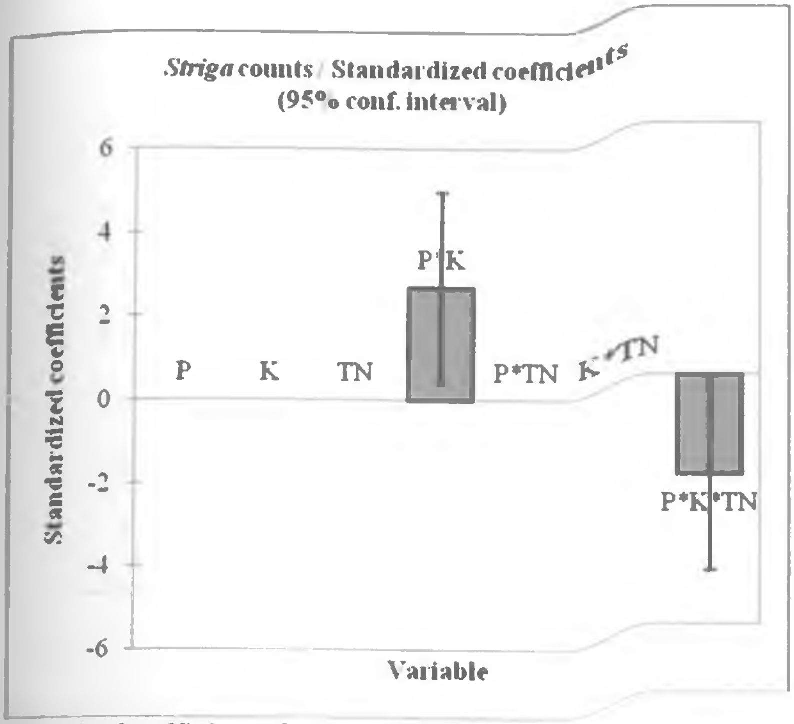


**Fig 3.2:** Coefficients for regression model:

*Striga* counts = 11.14+3.47*P*K-32.54*P*K*TN ($R^2 = 0.30$)

The regression model showed that when other factors are held constant, *Striga* number increases by 3.47 if interaction of phosphorus and potassium increases by 1 unit. One unit increase in potassium, nitrogen and phosphorus with other factors held constant reduced *Striga* numbers by 32.54

The regression analysis showed that the interactions of potassium by *Striga* counts and phosphorus by *Striga* counts contributed significantly ($P \leq 0.05$) to the explanation of variation in the number of capsules/plant as explained by their high standardized coefficients (Fig. 3.3).

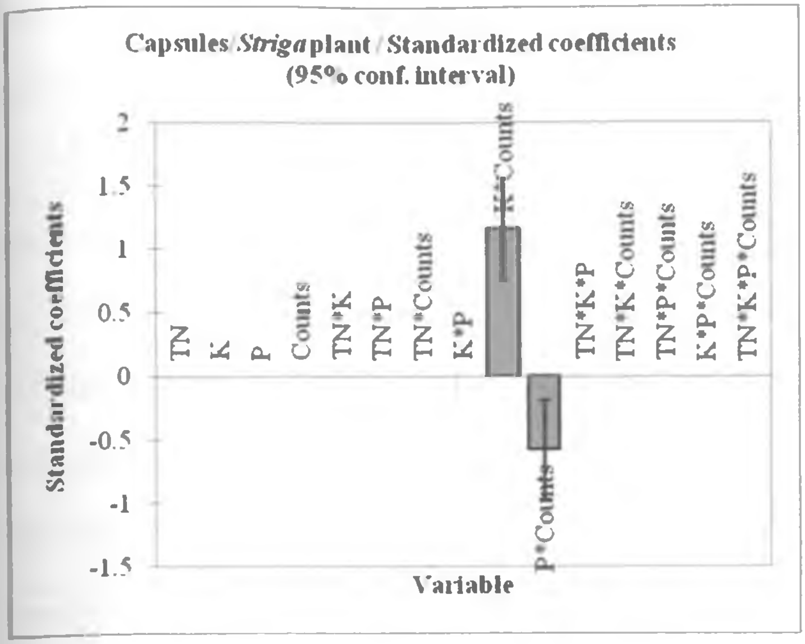


**Fig 3.3:** Coefficients for regression model:

Number of capsules/plant = 38.81+2.98*K*Counts-7.16E-02*P*Counts ($R^2 = 0.71$)

The analysis revealed that when other factors are held constant, capsules per plant increased by 2.98 if interaction of counts by potassium increased by 1 unit. Similarly, the interaction between *Striga* counts and P content reduced the number of capsules/plant when other factors were kept constant.

## 3.5 DISCUSSION

### 3.5.1 The *Striga* situation in the study areas and agronomic practices adopted

*Striga* infestation in 75% of the farmers' fields ranged from 11.67 to 53.42 *Striga* plants/$m^2$. This infestation level is very high according to MacOpiyo *et al.* (2010) who categorized infestation levels as low (1 to 4 *Striga* plants per $m^2$), medium (4 to 9 plants per $m^2$) and severe (> 9 *Striga* plants per $m^2$). These field observations confirm the farmers' perception of an increasing *Striga* infestation trend.

Two *Striga* species namely *S. asiatica* and *S. forbesii* were identified in the farmers' fields, with *S. forbesii* being found only in 10% of the fields. This finding agrees with findings of Mbwaga and Obilana (1993) and MacOpiyo *et al.* (2010) who reported the two *Striga* species in Dodoma and Morogoro regions of Tanzania. The majority of the interviewed farmers reported that *Striga* infestation levels had increased over time and that they first saw *Striga* in the last 5 years. The increasing trend of *Striga* infestation may be attributed to the decline in soil fertility and drought associated with climate change. In addition, agronomic practices for the control of *Striga* have not yet found large scale application on farmers' fields. This could be attributed to the fact that most of the benefits of the recommended control options are only realized after several seasons. These views are partly related to the view that increased intensity of the *Striga* problem in Africa is associated with both environmental and anthropogenic factors (Kroschel, 1999). A drastic change in the farming system from shifting cultivation to more or less continuous monocropping of host plants is mainly responsible for the increase in *Striga* infestation and damage (Berner *et al.*, 1996). Similarly, high and persistent infestation levels (80–90%) of farmers' fields have been reported for sorghum and maize fields in Africa (Dugje *et al.*, 2006; Parker, 2009). Therefore, many years of emphasis on *Striga* control in research and extension have apparently not resulted in effective management of the *Striga* problem.

The most mentioned control options identified by farmers included crop rotation, hand-pulling, and deep tillage. It is generally accepted that cereal rotation with trap crops (mostly legumes) and hand-pulling to prevent further seedbank build up are perhaps the most important components of sustainable, integrated *Striga* management in cereals (Berner *et al*., 1996; Ransom, 1999). In the current study, deep tillage was cited by farmers in both sites as one of the control measures for *Striga.* This technique was earlier suggested by Parker (1991). Farmers did not consider intercropping as a management option for *Striga* control. Use of resistant host crop varieties for *Striga* control was not practiced in any of the two communities. This is probably related to the non-availability of sorghum varieties that combine high levels of stable resistance to *Striga* with acceptable agronomic and grain characteristics, wide adaptation and resistance to major pests and diseases. Conventional breeding and variety testing have not produced crop varieties that have shown stable resistance in heavily infested fields (Kanampiu *et al.* 2003). Regression analysis indicated that a shift from sole cropping to intercropping reduced *Striga* infestation and reproduction. Similar observations were previously reported by Singh and Emechebe (1991) and Van Mourik (2007).

Among the sorghum production constraints mentioned by farmers at Melela, *Striga* was ranked the second to rainfall. It is however worth noting that moisture stress predisposes sorghum plants to *Striga* attack (Ejeta, 2007), making it difficult to separate moisture stress effects from *Striga* effects.

Farmers considered *Striga* seed dissemination by sorghum seed, animals, wind and run-off as the major factor that has exacerbated the *Striga* problem. This agrees with the findings of Berner *et al.* (1994) who reported that *Striga* seeds were mostly disseminated through contaminated host crop seeds and by cattle. Berner *et al*., (1996) recommended that the first step in reducing *Striga* damage is to prevent dispersal of the seeds into uninfested fields by restricting cattle movement from infested to *Striga* free areas and by planting uncontaminated crop seeds.

The results revealed that farmers were getting very low yields and the soils of the surveyed fields were poor in nitrogen and organic carbon. This may be attributed to the type of cropping practices that are used by farmers. Sorghum production systems based on mono-culture with long-term limited use of fertilizers have led to low soil fertility which is not only generating the *Striga* problem, but is also a major constraint to cereal production in Tanzania. It has been reported that soil nutrient depletion in African cropping systems has expanded rapidly due to land use intensification and the lack of use of mineral and organic fertilizer inputs (Ransom, 2000; Schlecht *et al.*, 2006).

### 3.5.2 Interaction effect of agronomic practices on soil chemical characteristics and number of capsules/plant

The reduction in the number of *Striga* capsules per plant as one moved from sole planting to intercropping could be due to improvement in soil N and OC, reduction in K and P, and increased shading effect on *Striga*. Tenebe and Kamara (2002) observed that *Striga* dry matter and the number of emerged *Striga* plants were significantly reduced when sorghum was intercropped with groundnut varieties. Similarly, Singh (1991) and Singh and Emechebe (1991) achieved greater *Striga* suppression when cowpea was planted close to sorghum. The reduction in soil K and P when one moved from sole planting to intercropping could be due to increased competition for nutrients between the crops. The competition for nutrients due to intercropping was earlier reported by Abunyewa and Padi (2003).

Most of the sorghum varieties grown by farmers are local land races that mature late and produce sprouts after harvest on which the *Striga* plants continue to parasitize and produce seeds. These increases the Striga seed bank in the soil and sustain the level of infestation. A similar observation was reported by Dugje *et al.* (2009). Hence, there is need for improved early maturing and *Striga* resistant sorghum varieties.

### 3.5.3 Interaction effect of soil chemical characteristics on *Striga* counts and reproduction

The higher numbers of *Striga* and capsules/plant observed in farmers' fields could be due to the high soil K content. Potassium was positively associated to the *Striga* counts and the number of capsules/plant. Since N level was very low, K could have enhanced stimulant activity and increased the maximum number of emerged *Striga* plants and number of *Striga* capsules/plant. Raju *et al.* (1990) and Farina *et al.* (1985) observed that the application of potassium in the absence of N promoted stimulant activity in the host, leading to increased *Striga* incidence whereas the presence of phosphorus did not have an effect on *Striga* seed germination and infestation. The regression model showed that the interaction of phosphorus and potassium increased *Striga* counts while the interaction of phosphorus and *Striga* plants reduced the number of *Striga* capsules/plant. The mechanism by which phosphorus reduced *Striga* reproduction has not been established.

## 3.6 CONCLUSION

*Striga* infestation levels in the study areas were invariably severe. There is low adoption of recommended *Striga* control methods such as hand-pulling and intercropping. The use of resistant varieties is not practiced at all while few farmers use fertilizer inputs. The levels of organic carbon, moisture and total nitrogen in farmers' fields were generally very low while available phosphorus and potassium were generally high. Moderate to high K levels in the *Striga* infested soils coupled with low N may enhance *Striga* reproduction and seed bank replenishment, resulting in increased *Striga* infestation in sorghum fields.

# CHAPTER 4

# INFLUENCE OF DIFFERENT SOURCES OF NUTRIENTS ON *STRIGA ASIATICA* REPRODUCTION, SORGHUM YIELD AND SOIL PHYSICAL-CHEMICAL CHARACTERISTICS

## 4.1 Abstract

The measures for *Striga* management are hindered by a unique survival strategy of the weed, whereby it produces large amount of seeds. Therefore, prevention of further build up of the *Striga* seed bank through control measures remains an essential component in *Striga* control. High soil nitrogen has been demonstrated to suppress *Striga* germination and attachment but its effect on *Striga* reproduction has not been well studied. Therefore, influence of organic and inorganic fertilizers on *Striga* reproduction and sorghum grain yield was studied for two consecutive years (2009/2010 and 2010/2011) at Hombolo Research Station-Dodoma, Tanzania. Farmyard manure (5.9 tons/ha equivalent to 50 kg N/ha), chicken manure (2.5 tons/ha equivalent to 50 kg N/ha), urea (50 kg N/ha) and triple superphosphate (TSP) (40 kg P/ha) were tested on sorghum variety Macia in a randomized complete block design replicated four times. Data collected were *Striga* numbers, *Striga* biomass, number of capsules/plant, *Striga* seeds/plant, sorghum plant height, sorghum biomass and sorghum grain yield. *Striga* biomass and *Striga* numbers were negatively correlated with sorghum grain yield. Plots supplied with chicken manure, urea and TSP had significantly fewer capsules per plant than farmyard manure treated and control (without fertilizer application) plants. Chicken manure application increased sorghum grain yield relative to all other treatments. Urea, TSP and farmyard manure did not affect sorghum growth and yield parameters. In most cases, chicken manure and farmyard

manure significantly increased the cation exchange capacity, pH, organic carbon, P, Mg, Zn and Fe content relative to the control and inorganic fertilizer treatments. Urea treated plots had significantly lower pH than chicken manure and farmyard manure treated plots. Results of this study show that, fertilizers have the potential to reduce *Striga* reproduction. Even though fertilizers play a significant role in *Striga* reproduction, calculations of the seed production per *Striga* plant indicated that considerable amounts of seeds (e.g. 33241 CHM to 58784 FYM) in 2010/2011 were still added to the soil. Therefore, need to combine with other control methods. Chicken manure can be used to improve sorghum production and soil fertility.

### 4.2 Introduction

Grain sorghum is mainly cultivated in areas where rainfall is insufficient for maize, wheat and rice production. The water requirement for dry matter production by sorghum is considerably less than that of maize and most other grain crops (Shiringani, 2005). Sorghum grows successfully even in areas where the average rainfall is as low as 300 to 400 mm (Hassan *et al.*, 2006). The low water requirement and ability to withstand drought make sorghum a crop of choice in areas experiencing low and sometimes unreliable rainfall (Kwacha, 2001).

However, the production of this important crop is threatened by soil infertility, drought, diseases and the parasitic weed, *Striga* (Kabambe *et al.*, 2007). A major pest in Africa is a parasitic plant of the genus *Striga* (Ayongwa *et al.*, 2010). Despite many years of research, *Striga* still remains a weed of economic importance affecting livelihoods of millions of people in Africa (Franke *et al.*, 2006). The weed is responsible for keeping crop productivity in many regions of Africa below subsistence levels (Dudje *et al.*, 2008). *Striga* occurs in Sub-tropical areas with an annual rainfall ranging from 300 to 1200 mm. However, it may be able to adapt to agro-climatic conditions outside its current distribution range and to other crop species (Mohamed *et al.*, 2006).

A number of studies found that *Striga* infestation decreased with application of organic or inorganic fertilizers (Lagoke *et al.*, 1991; Kwacha, 2001; Ahonsi *et al.*, 2002, 2004; Patil, 2007; Avav *et al.*, 2009; Hassan *et al.*, 2006). However, all these studies did not provide any insight into the influence of fertilizers on *Striga* reproduction and long term effect on the *Striga* seedbank. In a study, Lagoke *et al.* (1991) observed that application of high fertilizer dosages of up to 120 kg N/ha resulted in 93% reduction in *Striga* incidence. Plots treated with poultry manure had significantly higher *Striga* emergence than urea treated and the non-treated control plots (Ikie *et al.*, 2007). Parker (1984) reported that nitrogen tended to reduce the production of stimulants (strigol) by the host crop and delay *Striga* emergence. Riches (1998) reported that the timing of fertilizer applications even in small doses was effective on the plant's ability to cope with *Striga*.

Van Mourik (2007) reported that application of 2 ton/ha of organic manure did not have a significant effect on *Striga* seed production and long-term effect on *Striga* seed bank. However, one study on a single fertilizer type cannot be used to generalize the influence of fertilizers on *Striga* reproduction and long-term effect on seed bank. Therefore, the current study was conducted to determine the influence of both organic and inorganic fertilizers on *Striga* reproduction, sorghum grain yield and soil chemical characteristics.

### 4.3 Materials and methods

#### 4.3.1 Experimental site

Two years' (2009/2010 to 2010/2011) field trials were conducted at Hombolo Research Station, situated 40 km off Dodoma town, the capital city of Tanzania. The site is semi-arid, characterized by erratic and unreliable rainfall with an annual average rainfall ranging from 400 to 750 mm and a mean annual temperature of $30^0$ C (URT, 2002). The unreliability of rainfall and its high intensity over a short period of time (December to February) is an important factor in determining the land use pattern. The rainy season is from November to April with a long dry season from May to October. The soil type of the area can be described as thin stony soils with predominantly sand or sandy clay (URT, 2002). Fig. 4.1 represents the rainfall (mm) during the cropping season of 2010 and 2011 at Hombolo Research Station.

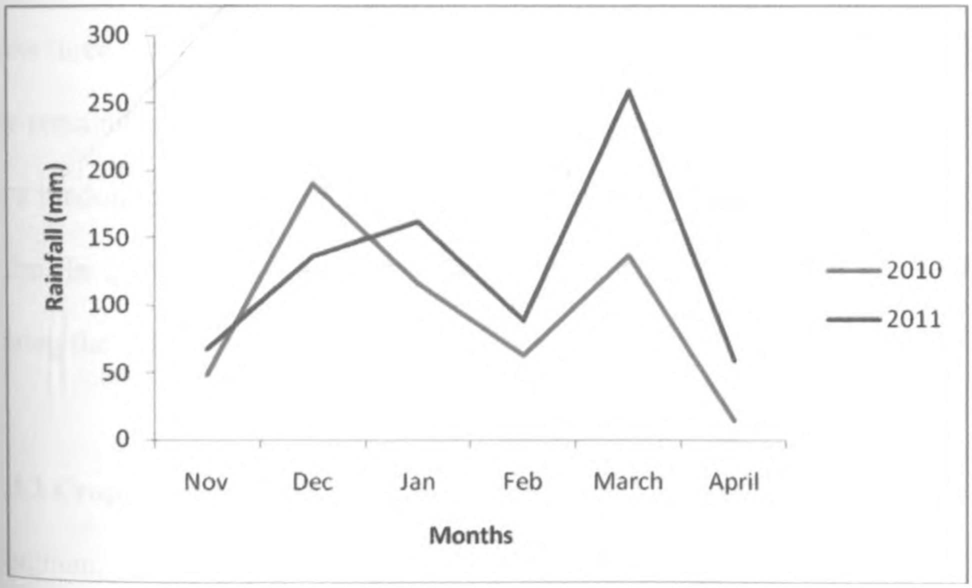


**Fig 4.1:** Rainfall (mm) at Hombolo during 2010 and 2011 cropping seasons

Prior to manure application, samples of organic manures were collected and analyzed for pH, organic carbon, N and P at Sokoine University of Agriculture Soil Laboratory (Table 4.1).

**Table 4.1:** Composition of major nutrients in organic manures used in the trial

| | | | | Nutrient composition | |
|---|---|---|---|---|---|
| Cropping season | Type of manure | pH | OC (%) | N (%) | P (mg/kg) |
| 2009/2010 | Chicken manure | 7.4 | 32.58 | 2.02 | 0.74 |
| | Farmyard manure | 6.7 | 12.65 | 0.84 | 0.14 |
| 2010/2011 | Chicken manure | 7.6 | 32.62 | 0.04 | 0.69 |
| | Farmyard manure | 6.9 | 12.63 | 0.82 | 0.16 |

*OC = organic carbon

### 4.3.2 Treatments and experimental design

The treatments consisted of 40 kg P/ha applied as triple superphosphate (TSP), urea at 50 kg N/ha, chicken manure (2.5 tons/ha) and farmyard manure (5.9 tons/ha). Each of the manure rates provided an equivalent of 50 kg N/ha. Organic fertilizers were incorporated into the experimental plots three weeks prior to planting while 30% of inorganic fertilizers were applied at sowing and the remaining 70% were applied three weeks after crop emergence. All treatments were laid out in a randomized complete block design replicated four times. Experimental plot size was 5 m x 3.2m. In 2010/2011 cropping season, the treatments were placed in the same plots they were during the 2009/2010 season.

### 4.3.3 Crop management

Sorghum, variety Macia was planted on 17 (2009/2010) and 11 (2010/2011) January, in a field naturally infested with *Striga asiatica* at Hombolo Research Station. The field was considered a sick plot due to previous work on *Striga* (Letayo, personal comm.) Sorghum was hand planted at a distance of 0.8 m x 0.3 m with four to six seeds per hole. Sorghum plants were then thinned to two plants per hole at two weeks after planting (WAP). Throughout the growing season, experimental plots were kept free of weeds other than *Striga asiatica* using hand hoe and hand pulling methods. At 4 WAP, endosulfan was applied at a rate of 350 g a.i/ha to control stem borers and other insects pests. Bird scarers were employed to protect the crop from bird attack at panicle initiation to harvest.

### 4.3.4 Data collection

*Plant measurements*

The height and above ground biomass of sorghum was measured at 4 WAP, flowering and harvest stages. Five randomly selected plants within the middle rows in each plot were used to determine plant height. Panicle length was determined just before harvest by measuring the lengths of five randomly selected plants in each plot. Sorghum grains were harvested at maturity from a net plot area of 4 $m^2$ (two middle rows). After harvesting, the panicles from each plot were threshed, winnowed and the seed dried to approximately 14% moisture content and weighed. The yield was expressed in kilograms per hectare.

*Striga* plant counts were done every two weeks in each experimental plot after *Striga* emergence. Total dry weight of *Striga* plants/$m^2$ was determined by harvesting all *Striga* plants in a plot and drying in an oven at $80^0$ C for 48 hours in paper bags. *Striga* reproduction was determined by sampling 10 mature but unopened, green seed capsules from five randomly selected *Striga* plants in each plot (i.e two seed capsules/plant) just before the harvest and packed separately in paper envelopes. These seed capsules were air dried for one week, weighed and the final weight determined by deducting 10% of the weight as a correction factor for unremovable trash. The average weight per capsule was divided by 5 x $10^{-6}$ (average *Striga* seed weight, Berner *et al.* 1997) to get an estimate of the seed production per capsule. The number of capsules per plant was counted for estimation of fecundity (seed production per plant).

*Soil physical characteristics*

Soil moisture content was determined at flowering and maturity stages. Soil moisture content was determined using bulk density method. Bulk density measurements were done using bulk density core sampler as described by Blake (1965). Undisturbed core (5.7cm diameter, 5.2cm high) samples from 0 - 20 cm depth were collected from the profiles dug in each of the experimental plot where different fertilizers were applied. Soon after taking the cores, they were taken to the laboratory and their weights were taken. The cores were then placed in an oven at 105°C and dried until constant weight was attained. Then the bulk density and soil moisture content was calculated as:

$$\text{Bulk Density} = \frac{\text{Oven dry weight of soil (g)}}{\text{Volume of soil (cm}^3\text{)}}$$

$$\text{\% Moisture (volume basis)} = 100 \times \frac{\text{(moist soil weight (g) - oven dry soil weight (g))}}{\text{Soil volume (cm}^3\text{)}}$$

*Soil chemical characteristics*

Soils were sampled at 0 – 20 cm depth before and at four weeks after fertilizer application using a 5 cm diameter auger. Prior to planting, soil samples were collected from five points in the whole experimental area along a diagonal using a 5 cm diameter auger and bulked to form a composite sample. At 4 WAP, soil samples were collected from each experimental plot by randomly sampling three points within the plot and bulking into a composite sample. Soil pH was determined in KCl as described by McLean (1982). Organic carbon was determined by wet oxidation method (Nelson and Sommers, 1982). Available Fe, Zn and Cu were extracted and determined by the atomic absorption spectrophotometer (AAS) method (AOAC, 1995). Total soil nitrogen (N) was determined by micro-Kjeldahl digestion (Bremner and Mulvaney, 1982). Available phosphorus (P) was determined by the Bray 1 method (Bray and Kurtz, 1945). Cation exchange capacity (CEC) was determined via the neutral ammonium acetate saturation method (Thomas, 1982). Exchangeable bases $K^+$, $Ca^{2+}$, and $Mg^{2+}$ displaced by ammonium acetate extracts were determined by an atomic adsorption spectrophotometer (Thomas, 1982).

#### 4.3.5 Data analysis

The data collected were subjected to analysis of variance (ANOVA) using GenStat ($12^{th}$ edition). Treatment mean comparisons were done using the least significant difference test at 5% probability level. Correlation analyses between *Striga* numbers, *Striga* biomass, *Striga* capsules/plant, sorghum grain yield and sorghum biomass yield were done using SPSS software package (Version 15). Prior to analysis, values of emerged *Striga* plants were square root $(x + 0.5)^{1/2}$ transformed to normalize data (Gomez and Gomez, 1984).

## 4.4 RESULTS

### 4.4.1 Effect of fertilizers on *Striga* numbers

Fertilizer treatments had a significant ($P \leq 0.05$) effect on *Striga* numbers at 9 and 11 WAP for 2010/2011 (Table 4.2). Addition of fertilizers did not have a significant effect on the *Striga* numbers in 2009/2010 season at all sampling periods and in 2010/2011 season at 13 and 15 WAP. In 2010/2011, at 9 WAP farmyard manure treated plots had significantly higher *Striga* counts/$m^2$ than all other treatments at 9 WAP. At 11 WAP, farmyard manure had significantly higher *Striga* counts/$m^2$ than urea treated plots. The overall mean number of *Striga* plants/$m^2$ ranged from 2.15 (9 WAP) to 4.62 (15 WAP) in 2009/2010 season and from 3.43 (9 WAP) to 7.90 (15 WAP) in 2010/2011 season (Table 4.2).

**Table 4.2:** The effect of fertilizers on *Striga* counts (number per $m^2$) at Hombolo in 2009/2010 and 2010/2011 cropping seasons

| | **Long rains, 2009/2011** | | | |
|---|---|---|---|---|
| Treatment | 9 WAP | 11 WAP | 13 WAP | 15 WAP |
| Control | 1.93 | 2.78 | 3.82 | 4.21 |
| Farmyard manure | 2.22 | 3.80 | 4.96 | 5.68 |
| Chicken manure | 2.91 | 4.06 | 5.09 | 5.02 |
| Urea | 1.13 | 1.72 | 2.46 | 2.73 |
| TSP | 2.58 | 3.33 | 4.81 | 5.48 |
| LSD ($P \leq 0.05$) | NS | NS | NS | NS |
| CV (%) | 37.90 | 37.50 | 30.70 | 33.20 |
| | **Long rains, 2010/2011** | | | |
| Control | 2.77 | 5.19 | 7.89 | 8.63 |
| Farmyard manure | 5.76 | 7.26 | 8.63 | 8.63 |
| Chicken manure | 3.31 | 5.17 | 6.22 | 6.36 |
| Urea | 1.84 | 3.78 | 6.11 | 6.46 |
| TSP | 3.46 | 6.99 | 9.15 | 9.40 |
| LSD ($P \leq 0.05$) | 2.19 | 3.16 | NS | NS |
| CV (%) | 41.50 | 36.10 | 31.70 | 31.10 |

*Control = zero application of fertilizer; * WAP = weeks after planting;
*TSP = triple-superphosphate; NS = mean values not significant different

### 4.4.2 Effect of fertilizers on *Striga* biomass, capsule numbers and fecundity

There were significant ($P \leq 0.05$) differences in *Striga* biomass between treatments in both seasons (Table 4.3). Urea treated plots had significantly lower *Striga* biomass than farmyard and chicken manure treated plots in 2009/2010 season. In 2010/2011 season, the control plots had significantly higher *Striga* biomass than plots supplied with chicken manure. Mean *Striga* biomass ranged from 16.3 to 45.5 g/m$^2$ in 2009/2010 and 30.68 to 67.85 g/m$^2$ in 2010/2011.

Fertilizer application had a significant ($P \leq 0.05$) effect on the number of capsules/plant only during the 2010/2011 season. Plants supplied with chicken manure, urea and TSP had significantly fewer capsules per plant than farmyard manure treated and control (without fertilizer application) plants. The overall mean number of capsules/plant ranged from 55.14 in 2009/2010 season to 94.79 in 2010/2011 season. No differences were noted on *Striga* fecundity (seeds/plant) among all the treatments in 2009/2010 season. However, mean *Striga* fecundity ranged from 35988 to 64390. In 2010/2011 season, farmyard manure, chicken manure, urea and TSP treated plots had significantly lower *Striga* fecundity relative to the control. During this season, chicken manure, urea and TSP treated plots had significantly lower *Striga* fecundity than farmyard manure treated plots (Table 4.3).

**Table 4.3:** Effect of fertilizers on *Striga* biomass, number of capsules and fecundity at Hombolo in 2009/2010 and 2010/2011 cropping season

| Treatment | Long rains, 2009/2010 | | | Long rains, 2010/2011 | | |
|---|---|---|---|---|---|---|
| | Biomass ($g/m^2$) | Capsules/plant | Fecundity (seeds/plant | Biomass ($g/m^2$) | Capsules/plant | Fecundity (seeds/plant) |
| Control | 30.81 | 68.68 | 64390 | 67.85 | 137.57 | 93826 |
| FYM | 40.36 | 69.68 | 63683 | 47.10 | 117.10 | 58784 |
| CHM | 45.44 | 42.62 | 37723 | 30.68 | 66.35 | 33241 |
| Urea | 16.31 | 41.25 | 35988 | 49.83 | 81.85 | 38961 |
| TSP | 22.45 | 53.45 | 46127 | 52.70 | 71.07 | 39162 |
| LSD ($P \leq 0.05$) | 19.18 | NS | NS | 35.57 | 32.21 | 18618.5 |
| CV (%) | 40.1 | 40.9 | 39.7 | 46.4 | 22.1 | 22.9 |

*Control = zero application of fertilizer; FYM = farmyard manure; CHM = chicken manure
*TSP = triple-superphosphate; NS = mean values not significant different

### 4.4.3 Effect of fertilizers on sorghum height

The mean sorghum height was significantly affected by fertilizer application ($P \leq 0.05$) during both season and at all sampling stages (Table 4.4). During both seasons, chicken manure treated plots had significantly higher sorghum plant height than the control plots at all sampling periods and plots treated with farmyard manure, urea and TSP at all sampling periods except at harvest in 2009/2010 season. Control plots, urea, TSP and farmyard manure treated plots were not significantly different in sorghum plant height at flowering and harvest stages in both seasons. In contrast, at 4 WAP, TSP treated plots had higher plant height than urea treated and control plots.

**Table 4.4:** The effect of fertilizers on the height of sorghum (cm) plants in 2009/2010 and 2010/2011 cropping season

| | Long rains, 2009/2010 | | | Long rains, 2010/2011 | | |
|---|---|---|---|---|---|---|
| Treatment | at 4 WAP | at flowering | at harvest | at 4 WAP | at flowering | at harvest |
| Control | 29.00 | 64.75 | 86.45 | 47.05 | 77.50 | 102.80 |
| Farmyard manure | 33.45 | 68.75 | 83.45 | 61.80 | 88.05 | 100.00 |
| Chicken manure | 48.25 | 85.50 | 95.85 | 87.15 | 114.15 | 117.9 |
| Urea | 23.75 | 60.00 | 88.70 | 49.55 | 81.95 | 106.60 |
| TSP | 35.60 | 70.75 | 88.60 | 58.85 | 88.20 | 107.4 |
| LSD ($P \leq 0.05$) | 3.98 | 14.44 | 8.06 | 8.34 | 15.38 | 6.89 |
| CV (%) | 7.60 | 13.40 | 5.90 | 8.90 | 11.10 | 4.20 |

*Control = zero application of fertilizer; TSP = triple-superphosphate

* WAP = weeks after planting

### 4.4.4 Effect of fertilizers on sorghum above ground biomass

The application of chicken manure significantly ($P \leq 0.05$) increased sorghum above ground biomass compared to the control at 4 WAP and flowering stages of sorghum growth in both seasons (Fig. 4.2 and 4.3). During 2009/2010, all treatments were not significantly different in sorghum biomass at harvest stage. Control plots, farmyard manure, urea and TSP treated plots were not significantly different in sorghum biomass at four WAP and flowering stage in 2009/2010. Addition of TSP and chicken manure significantly improved sorghum above- ground biomass in 2010/2011 compared to the control plots at harvest stage in 2010/2011 season. In the same season, chicken manure treated plot had significantly higher sorghum biomass than urea treated and control plots at 4 WAP.

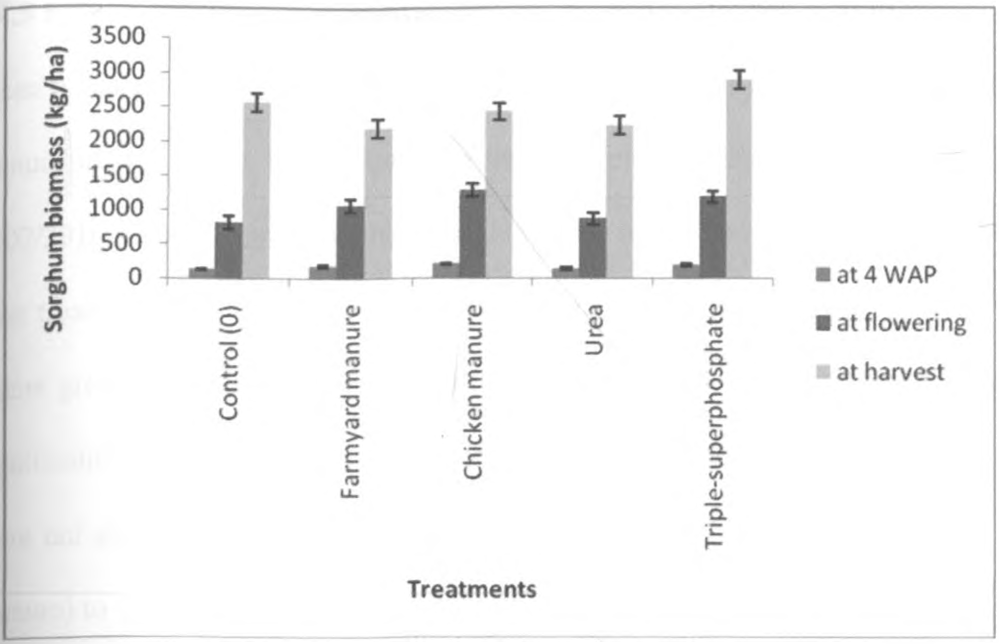


**Fig. 4.2:** Effect of fertilizers on sorghum above-ground biomass in 2009/2010 cropping season.
*The bars represent SE values

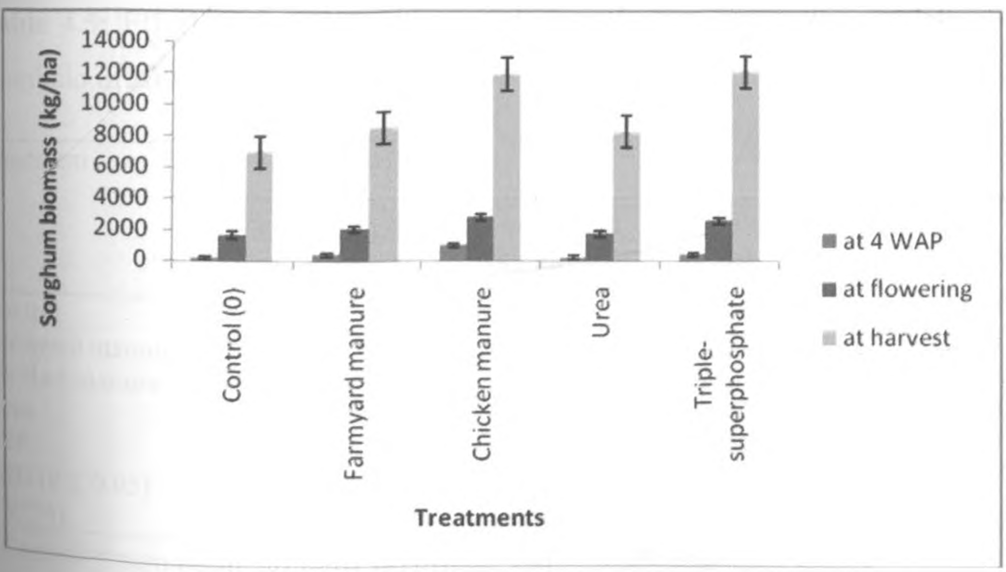


**Fig. 4.3:** Effect of fertilizers on sorghum above-ground biomass in 2010/2011 cropping season.
*The bars represent SE values

### 4.4.5 Effect of fertilizers on panicle length and grain yield of sorghum

Mean panicle length was significantly ($P \leq 0.05$) affected by fertilizers in both seasons. Chicken manure treated plants had longer panicles than plants treated with the rest of the fertilizers in 2009/2010 season. Triple-superphosphate treated plants had longer panicles than the control and urea treated plants in 2010/2011 season. Plants grown in 2010/2011 had longer panicles than plants grown in 2009/2010 (Table 4.5). In both seasons, application of chicken manure gave significantly higher sorghum grain yields than the control and all the other treatments which were not significantly different in grain yield. The grain yields ranged from 288.30 (farmyard manure) to 924.20 kg/ha (chicken manure) in 2009/2010 season and from 1912 (control) to 6388 kg/ha (chicken manure) in 2010/2011 season.

**Table 4.5:** Effect of fertilizers on panicle length (cm) and grain yield (kg/ha) of sorghum at Hombolo in 2009/2010 and 2010/2011 cropping seasons

| Treatment | 2009/2010 | | 2010/2011 | |
|---|---|---|---|---|
| | Panicle length (cm) | Grain yield (kg/ha) | Panicle length (cm) | Grain yield (kg/ha) |
| Control | 20.50 | 409.20 | 22.53 | 1912.00 |
| Farmyard manure | 18.58 | 288.30 | 23.33 | 2525.00 |
| Chicken manure | 23.35 | 924.20 | 23.68 | 6388.00 |
| Urea | 19.50 | 444.40 | 22.20 | 2200.00 |
| TSP | 19.70 | 322.60 | 25.43 | 3400.00 |
| LSD ($P \leq 0.05$) | 3.14 | 293.20 | 2.36 | 1558.40 |
| CV (%) | 10.00 | 39.80 | 6.50 | 30.80 |

*Control = zero application of fertilizer; TSP = triple-superphosphate

### 4.4.6 Correlations between *Striga* numbers, biomass, capsules/plant, sorghum biomass, panicle length and grain yield

Both *Striga* number and *Striga* biomass were positively correlated with the number of capsules per plant in both years (Table 4.6 and 4.7). Sorghum above-ground biomass and panicle length were significantly positively correlated with sorghum grain yield in both seasons. Grain yield was significantly negatively correlated with *Striga* counts and number of capsules/plant in 2009/2010 season and *Striga* counts, number of capsules/plant and *Striga* biomass in 2010/2011 season. Sorghum biomass was significantly negatively correlated with *Striga* biomass and number of capsules/plant in 2009/2010 season. *Striga* biomass, number of capsules and *Striga* numbers were negatively correlated with sorghum panicle length in both seasons.

**Table 4.6:** Pearson correlations between variables in 2009/2010 cropping season

| | Sorghum above-ground biomass (kg/ha) | Panicle length (cm) | Grain yield (kg/ha) | *Striga* counts/m$^2$ | *Striga* biomass/m$^2$ | No. of *Striga* capsules/plant |
|---|---|---|---|---|---|---|
| Sorghum above-ground biomass (kg/ha) | 1.00 | | | | | |
| Panicle length (cm) | 0.44 | 1.00 | | | | |
| Grain yield (kg/ha) | 0.47* | 0.67** | 1.00 | | | |
| *Striga* counts/m$^2$ | -0.34 | -0.12 | -0.50* | 1.00 | | |
| *Striga* biomass/m$^2$ | -0.54* | -0.14 | -0.33 | 0.75* | 1.00 | |
| No. of capsules/plant | -0.08 | 0.53* | -0.50* | 0.35 | 0.35 | 1.00 |

*Correlation is significant at the $p \leq 0.05$ level

**Correlation is significant at the $p \leq 0.01$ level

**Table 4.7:** Pearson correlations between variables in 2010/2011 growing season

| | Sorghum above-ground biomass (kg/ha) | Panicle length (cm) | Grain yield (kg/ha) | *Striga* counts/m$^2$ | *Striga* biomass/m$^2$ | No. of capsule/plant |
|---|---|---|---|---|---|---|
| Sorghum above-ground biomass (kg/ha) | 1.00 | | | | | |
| Panicle length (cm) | 0.28 | 1.00 | | | | |
| Grain yield (kg/ha) | 0.72** | 0.46* | 1.00 | | | |
| *Striga* counts/m$^2$ | -0.28 | -0.02 | -0.45* | 1.00 | | |
| *Striga* biomass/m$^2$ | -0.34 | -0.08 | -0.46* | 0.68** | 1.00 | |
| No. of capsule/plant | -0.50* | -0.38 | -0.53* | 0.31 | 0.46* | 1.00 |

*Correlation is significant at the $p \leq 0.05$ level

**Correlation is significant at the $p \leq 0.01$ level

### 4.4.7 Effect of fertilizers on soil physical-chemical characteristics

Initial soil analysis results from the experimental site revealed that the soil was very low in total nitrogen and organic carbon (Table 4.8). Available phosphorus was at medium level while K content was high. Other exchangeable Cations and micro-nutrients were at medium to low levels.

**Table 4.8:** Initial physical and chemical characteristics of soil at the experimental site in 2009/2010

| Parameter | value | level | Particle size | value |
|---|---|---|---|---|
| pH | 5.40 | Strong acidic | Sand (%) | 72 |
| OC (%) | 0.51 | Very low | Silt (%) | 3 |
| CEC (cmol/kg) | 15.60 | Medium | Clay (%) | 25 |
| Total N (%) | 0.07 | Very low | Textural class | Sandy clay |
| Available P (mg/kg) | 7.03 | Medium | | |
| K (mg/kg) | 0.68 | High | | |
| Mg (mg/kg) | 0.65 | Medium | | |
| Ca (mg/kg) | 0.79 | Medium | | |
| Zn (mg/kg) | 0.39 | Low | | |
| Fe (mg/kg | 3.38 | Medium | | |
| Cu (mg/kg) | 0.18 | Low* | | |

*Refer to the critical values in appendix 2

In 2009/2010 season, treatments caused significant changes in soil moisture, pH, CEC, P, K, and Zn, but not in total N, organic C, Ca, Mg, Fe and Cu. In 2010/2011 season, treatments caused significant changes in all the soil attributes measured except Ca (Table 4.9).

Plots treated with organic fertilizers retained significantly more moisture than control and plots treated with inorganic fertilizers in both seasons (Table 4.9). Urea treated plots had significantly lower pH than farmyard manure and chicken manure treated plots in 2009/2010 season. In 2010/2011 season, chicken and farmyard manure treated plots had significantly higher pH and OC than the control plots and plots treated with urea and TSP. During 2009/2010 season, chicken manure treated plots had significantly higher CEC content than control and farmyard manure treated plots. Chicken manure treated plots had higher CEC content than the control, urea and TSP treated plots in 2010/2011 season.

**Table 4.9:** Effect of fertilizers on soil physical- chemical characteristics (means of 2009/2010 and 2010/2011cropping seasons)

| Parameter | Long rains, 2009/2010 | | | | | |
|---|---|---|---|---|---|---|
| | Treatment | | | | | |
| | Control | FYM | CHM | TSP | UREA | LSD |
| Moisture (V %) | 10.11 | 12.98 | 13.07 | 11.07 | 10.60 | 1.88 |
| pH | 5.43 | 5.69 | 5.63 | 5.47 | 5.33 | 0.24 |
| OC (%) | 0.56 | 0.59 | 0.56 | 0.55 | 0.49 | NS |
| Total N (%) | 0.08 | 0.09 | 0.10 | 0.08 | 0.09 | NS |
| P (mg/kg) | 2.68 | 4.64 | 15.67 | 3.21 | 3.04 | 2.93 |
| CEC cmol/kg | 11.65 | 12.55 | 13.75 | 12.30 | 11.75 | 2.08 |
| K (mg/kg) | 0.58 | 0.73 | 0.67 | 0.58 | 0.57 | 0.11 |
| Mg (mg/kg) | 1.00 | 1.10 | 1.25 | 1.03 | 1.09 | NS |
| Ca (mg/kg) | 4.34 | 4.66 | 5.05 | 4.38 | 4.66 | NS |
| Zn (mg/kg) | 0.42 | 0.53 | 0.65 | 0.45 | 0.35 | 0.17 |
| Fe (mg/kg) | 11.28 | 11.64 | 11.15 | 11.46 | 11.28 | NS |
| Cu (mg/kg) | 1.31 | 1.39 | 1.35 | 1.31 | 1.31 | NS |
| | Long rains, 2010/2011 | | | | | |
| Moisture (V %) | 11.57 | 14.64 | 15.72 | 12.39 | 11.98 | 1.49 |
| pH | 5.62 | 7.04 | 6.65 | 5.61 | 5.60 | 0.32 |
| OC (%) | 0.55 | 0.75 | 0.74 | 0.51 | 0.48 | 0.15 |
| Total N (%) | 0.07 | 0.09 | 0.11 | 0.08 | 0.08 | 0.11 |
| P (mg/kg) | 4.74 | 21.25 | 71.27 | 18.57 | 7.72 | 10.10 |
| CEC cmol/kg | 12.73 | 14.13 | 14.63 | 12.80 | 12.45 | 1.51 |
| K (mg/kg) | 0.94 | 1.32 | 1.06 | 0.84 | 0.89 | 0.38 |
| Mg (mg/kg) | 0.94 | 1.34 | 1.75 | 1.21 | 1.29 | 0.30 |
| Ca (mg/kg) | 4.74 | 5.57 | 6.04 | 5.39 | 5.42 | NS |
| Zn (mg/kg) | 0.15 | 0.49 | 0.98 | 0.16 | 0.09 | 0.18 |
| Fe (mg/kg) | 6.26 | 5.42 | 7.98 | 6.93 | 6.16 | 0.77 |
| Cu (mg/kg) | 0.22 | 0.37 | 0.51 | 0.39 | 0.38 | 0.12 |

*LSD = least significant difference at 5% probability level; FYM = farmyard manure; TSP = triple superphosphate; CHM = chicken manure; Control = zero fertilizer application; Moisture (V %) is the mean of samples taken at flowering and maturity stages; NS = mean values not significant different

In both seasons, chicken manure application had significantly the highest soil P content (Table 4.9). No differences were noted in P content among the control, farmyard manure, urea and TSP treated plots in 2009/2010 season. In 2010/2011 season, farmyard manure and TSP treated plots had significantly higher P content than urea treated and control plots. No differences were noted in the soil K content among the control, urea, TSP and chicken manure treated plots in 2009/2010 season. However, farmyard manure supplied plots had significantly higher soil K content than the control, urea and TSP treated plots. Similar observations were noted during the 2010/2011 season. In 2010/2011 season, chicken manure treated plots had significantly highest Mg content relative to all the treatments. Farmyard manure, chicken treated plots had significantly higher Mg content than the control plots. Calcium content ranged from 4.34 (control) to 5.05 mg/kg (chicken manure) in 2009/2020 season and 4.74 (control) to 6.04 mg/kg (chicken manure) in 2010/2011 season.

In 2009/2010 season, chicken manure treated plots had significantly high zinc content than the control, TSP and urea treated plots (Table 4.9). Farmyard manure and chicken manure treated plots had significantly higher zinc content than the control, urea and TSP treated plots in 2010/2011 season. During this season, chicken manure treated plots had higher Zn content than FYM treated plots. During 2010/2010 season, chicken manure supplied plots had higher Fe content than the rest of the treatments. In 2010/2011 season, farmyard manure, chicken manure, urea and TSP treated plots had significantly higher Cu content than the control plots. Chicken manure treated plots had higher Cu content than urea and farmyard manure treated plots.

## 4.5 DISCUSSION

### 4.5.1 Fertilizer effects on *Striga* numbers and *Striga* biomass

Application of farmyard manure, chicken manure, urea and TSP fertilizers did not significantly affect *Striga* numbers at all sampling periods in 2009/2010 presumably due to the low organic carbon and nitrogen supply of the soil. Similar, results were also observed by Smaling *et al.*

in the soil K content among the control, urea, TSP and chicken manure treated plots in 2009/2010 season. However, farmyard manure supplied plots had significantly higher soil K content than the control, urea and TSP treated plots. Similar observations were noted during the 2010/2011 season. In 2010/2011 season, chicken manure treated plots had significantly highest Mg content relative to all the treatments. Farmyard manure, chicken treated plots had significantly higher Mg content than the control plots. Calcium content ranged from 4.34 (control) to 5.05 mg/kg (chicken manure) in 2009/2020 season and 4.74 (control) to 6.04 mg/kg (chicken manure) in 2010/2011 season.

In 2009/2010 season, chicken manure treated plots had significantly high zinc content than the control, TSP and urea treated plots (Table 4.9). Farmyard manure and chicken manure treated plots had significantly higher zinc content than the control, urea and TSP treated plots in 2010/2011 season. During this season, chicken manure treated plots had higher Zn content than FYM treated plots. During 2010/2010 season, chicken manure supplied plots had higher Fe content than the rest of the treatments. In 2010/2011 season, farmyard manure, chicken manure, urea and TSP treated plots had significantly higher Cu content than the control plots. Chicken manure treated plots had higher Cu content than urea and farmyard manure treated plots.

## 4.5 DISCUSSION

### 4.5.1 Fertilizer effects on *Striga* numbers and *Striga* biomass

Application of farmyard manure, chicken manure, urea and TSP fertilizers did not significantly affect *Striga* numbers at all sampling periods in 2009/2010 presumably due to the low organic carbon and nitrogen supply of the soil. Similar, results were also observed by Smaling *et al.*

(1991) and Kamara *et al.* (2007) who found that fertilizer application did not significantly affect *Striga* infestation. The reduction of *Striga* numbers at 9 and 11 WAP with application of urea in 2010/2011 could be due to the higher level of nitrogen supplied by urea that could have affected the production of *Striga* stimulants. Ikie *et al.* (2007) found that urea significantly lowered *Striga* emergence in the field, compared to an equivalent N dose of organic manure due to the faster release of N from the former than the latter.

The reduction in *Striga* biomass in plots treated with chicken manure in 2010/2010 is probably due to the higher quantity of nitrogen supplied by the chicken manure applied which affected *Striga* growth. It is not the quantity but the rate of release of the nitrogen that is essential for the negative effect that N has on *Striga* (Kranz *et al.*, 1998). Ayongwa (2011) observed that timing of fertilizer application is more important than the amount applied. While various authors showed that N application significantly suppressed *Striga* in cereal production, Bebawi (1981) noted that there was no consistent host plant response to N fertilization with regard to reduced *Striga* infestations and biomass. Such inevitable problems in N fertilizer application could explain inconsistencies on the effect of farmyard manure and chicken manure applied at the same rates in controlling *Striga* infestations. Sometimes high rates of N fertilizer produce high infestation levels and biomass in the farmers' fields (Ayongwa, 2006).

### 4.5.2 Fertilizer effects on the number of capsules per *Striga* plant and fecundity

Reduction in the number of capsules per *Striga* plant in 2010/2011 due to application of chicken manure and urea and the reduction in fecundity due to urea, chicken manure and farmyard manure application could be attributed to their nitrogen release in the soil. The N release could have improved sorghum N status and thereby adversely affected *Striga* growth and reproduction. An earlier study by Riches (1998) reported that N fertilizers reduced *Striga* reproduction and the load of attached parasites through their effect on the sorghum root. Nitrogen somehow modified the host's root stimulants by either considerably reducing the quantity or making exudates less active in eliciting *Striga* seed stimulation (Matusova *et al.*, 2005). Negative effects of TSP application on the number of capsules/plant and fecundity were observed in the current study. According to the available literature, this study may be the first one that observed such a relationship. Studies by Raju *et al.* (1990) and Farina *et al.* (1985) demonstrated no effect of phosphorus on *Striga* seed germination and infestation. However, none of these authors studied the relationship between phosphorus application and *Striga* reproduction. Therefore, the mechanism by which phosphorus application reduced the *Striga* reproduction in the current study is yet unclear. Evidently, there is a need for further study on the effect of P application on *Striga* reproduction.

### 4.5.3 Relationship between *Striga* numbers, biomass and capsule production

*Striga* numbers and biomass are good indicators for capsule production as indicated by the positive and significant correlations between these variables. Reduction in *Striga* numbers led to low biomass and consequently low number of seed capsules. These observations are in agreement with the findings by Haussmann *et al.* (2001) and Rodenburg *et al.* (2006a) who reported highly significant correlations between *Striga* biomass and *Striga* seed capsules. Carsky *et al.* (1994) concluded that the reduced number of capsule forming plants was related to *Striga* above-ground biomass rather than below-ground suppression. In the present study, it can be concluded that any fertilizer sources that reduce *Striga* numbers and biomass will cause a proportional reduction in seed production.

### 4.5.4 Long-term effect of fertilizers on *Striga* seed bank

Van Mourik *et al.* (2005) reported average densities of *Striga* seed bank to range from 1800 to 414600 seeds/m$^2$ based on a literature search. In this study, *Striga* seed number per plant ranged from 35988 (urea) to 64390 (control) in 2009/2010 and from 33241 (chicken manure) to 93826 (control) in 2010/2011. It would appear that for an initial seedbank of 414600/m$^2$, only about 5 *Striga* plants/m$^2$ (in 2010/2011) would be enough to completely replace the original seedbank if farmers were to continue planting without using fertilizers (as observed in chapter 3). In a situation where farmers were to use fertilizers like chicken manure as in 2010/2011, about 13 *Striga* plants/m$^2$ would be enough. In fact, these values of *Striga* number/m$^2$ are very common in infested fields. Based on these observations, it is concluded that just the use of fertilizers alone is not enough to reduce the *Striga* seed inputs. Integrating fertilizers with other control measures is therefore an important approach to preventing seed inputs into the soil.

### 4.5.5 Effect of fertilizers on sorghum growth parameters

The increase in sorghum plant height and biomass due to application of chicken manure and TSP might be due to an increase in major nutrients such as N and P for chicken manure and P for TSP. This finding is in agreement with work by Sunilkumar (2005) and Paturde *et al.* (2002) who noticed that application of chicken manure mixed with vermicompost recorded a significant increase in sorghum biomass. The low sorghum performance observed due to farmyard manure application could be caused by the fact that there was high *Striga* infestation in the plots. *Striga* severely stunts the growth of the host crop by intensive uptake of water, carbohydrates and other nutrients from the host (Gworgwor and Webber, 1991). Perhaps the amount of P released from farmyard manure was lower than in chicken manure. Phosphorus content ranged from 0.69 to 0.74 mg/kg in chicken manure and 0.14 to 0.16 mg/kg in farmyard manure.

### 4.5.6 Effect of fertilizers on sorghum grain yield and panicle length

The high grain yields obtained in this study due to chicken manure application could be due to high supply of nitrogen and available P. Ghosh *et al.* (2004) reported that approximately 74% of total P and 40% of total N in chicken manure were in available form and sorghum being a heavy feeder of nutrients particularly N, took N faster from the available pool of applied chicken manure. Musambasi *et al.* (2003) observed a reduction in *S. asiatica* plants and a direct increase in N level which is required for grain filling as the N level was increased. The increase in panicle length due to application of TSP in 2010/2011 could be due to P supplied by the fertilizer. Phosphorus is the most important nutrient element for seed production and ear or panicle improvement (Jones *et al.*, 2003).

Failure of urea to increase sorghum grain yield suggests that it may have been leached from the soil. The soil at Hombolo was composed of a high percentage of sand and very low organic carbon content hence, prone to leaching. The high rainfall observed at Hombolo during the 2010/2011 growing season may have washed away urea and caused the observed low yields. These results are in agreement with those obtained by Pierce *et al.* (2003) who observed low yields of sorghum as urea was washed out of sandy soils.

### 4.5.7 Effect of fertilizers on soil physical-chemical characteristics

There was improvement of soil moisture retention and soil nutrients due to application of organic manures. This could have been due to decomposition and mineralization which resulted in the release of several nutrients into the soil. This moisture retention attribute of the organic materials highlights the higher moisture content often recorded for soils with greater contents of organic matter and sustained growth of crops grown on them during periods of moisture stress. A similar conclusion has been made by several authors (Ghosh *et al.*, 2004; Quansah, 2010).

The increase in soil pH in organic manure treated plots might be due to the fact that farmyard manure and chicken manure materials had high pH. These results confirm earlier findings by Avav *et al.* (2009) who found increased pH due to application of poultry manure. This study also found that there was an increase in soil pH and OC in 2010/2011 compared to 2009/2010 growing season. It was also reported that the fields that were continuously applied with organic fertilizers showed an increase in soil pH and organic carbon (Avav *et al.*, 2009). The lowering of soil pH in inorganic fertilizers might be due to the fact that the most inorganic fertilizers supply $NH_4^+$ or result in its production. Upon oxidation $NH_4^+$ releases $H^+$ ions which are potential sources of acidity (Lalfakzuala *et al.*, 2008). Available P, OC, Mg, K, and Zn were high in plots treated with organic fertilizers, indicating that application of organic fertilizers significantly increased soil nutrient concentration, as reported by Ishaq *et al.* (2002).

## 4.6 CONCLUSION

The application of fertilizers has a potential for the control of *Striga asiatica* through reduced seed inputs in the soil. However, the tested treatments showed little possibility for effective elimination of the *Striga* seed bank with the use of only fertilizers. This strategy will not avoid *Striga* damage to cereal crops after a single year because considerable amounts of seeds will persist in the soil. It is suggested that integrating different control options such as fertilizer application with weeding of any *Striga* plants before they flower may achieve nearly complete prevention of seed bank input through shedding. The application of chicken manure improved sorghum grain yield and soil fertility. Therefore, it can be used as a source of nutrients in semi arid areas of Tanzania. However, enough chicken manure may not be available to farmers hence, the need for combined organic and inorganic fertilizers.

# CHAPTER 5

# EFFECT OF COMBINED FARMYARD MANURE AND UREA ON *STRIGA ASIATICA* REPRODUCTION AND SORGHUM GRAIN YIELD

## 5.1 Abstract

The witchweed (*Striga asiatica*) is a serious problem in fertility-depleted soils of Tanzania. It spreads quickly and its seed banks can remain in the soil for several years. Therefore, understanding *Striga* seed production is one of the key elements to management of this severe and difficult to control parasitic weed in African agricultural systems. A study was carried out in 2010/2011 at two locations (Hombolo and Melela) in Tanzania to determine the effect of combined farmyard manure and urea levels on *Striga* reproduction and sorghum grain yield. A factorial experiment was laid out in a randomized complete block design in fields that were naturally infested with *Striga asiatica*. The treatments consisted of farmyard manure rates equivalent to 0, 25, 50 and 60 kg N/ha and urea rates of 0, 25, 50 and 60 kg N/ha which were replicated three times. Sorghum variety Macia was used in the trials. Data collected were *Striga* numbers, *Striga* biomass, number of capsules/plant, *Striga* seeds/plant, sorghum biomass and sorghum grain yield. The results showed that combined farmyard manure with urea significantly reduced *Striga* numbers. At 50 and 60 kg N/ha FYM, application of urea at all rates significantly reduced *Striga* numbers. Application of 60 kg N/ha urea significantly reduced the *Striga* biomass relative to the control while the other rates did not have significant effects. Combined farmyard manure and urea significantly reduced *Striga* reproduction. For instance, the application of 50 kg N/ha or 60 kg N/ha urea with farmyard manure at 25 kg N/ha and above significantly reduced the number of capsules/plant compared to the control across the two sites. Application of 25 kg

N/ha (FYM) at zero level of urea increased *Striga* number/m$^2$, capsules/plant and fecundity. A combined application of farmyard manure with urea gave higher sorghum yields than application of inorganic fertilizer or organic manure alone. At Melela, combination of urea at 60 kg N/ha and farmyard manure at 60 kg N/ha (equivalent), increased yields by 278% compared to the control. This study shows that reduction in *Striga* reproduction can be achieved by combined application of farmyard manure with a moderate dose of inorganic fertilizer. In the short–term, small quantities of farmyard manure may increase *Striga* infestation and reproduction in heavily infested fields. Economic analysis revealed that application of urea alone at 25, 50 and 60 kg N/ha, respectively, had marginal rates of return of 31, 54 and 48%, respectively. A high marginal rate of return of 70% was obtained when urea at the rate of 60 kg N/ha was combined with farmyard manure at the equivalent rate of 60 kg N/ha. Farmyard manure applied alone at 25, 50 and 60 kg N/ha had negative net benefits. It is possible that in the long-term, continuous addition of farmyard manure can have suppressing effects on the *Striga,* improve fertility status of the fields and increase economic benefits.

## 5.2 Introduction

In Africa, the production of cereals such as sorghum is hampered by various abiotic and biotic constraints. Species of the plant-parasitic genus *Striga* (Orobanchaceae) represent the largest single biological constraints to food production in Africa (Hearne, 2009; Parker, 2009). *Striga* severely stunts the growth of the host crop by intensive uptake of water, carbohydrates and other nutrients from the host (Akiyama and Hayashi, 2006).

*Striga* has been a major constraint affecting cereal production in the semi arid, tropical and sub-tropical regions of Tanzania resulting in serious yield reductions (Masawe *et al.*, 2001). *Striga* species of economic importance observed in Tanzania include *Striga asiatica*, *S. forbesii* and *S. hermonthica* (Mbwaga and Ruches, 2000). Grain yield losses caused by *Striga* have been reported to be 25% to 100% depending on the infestation level (Bayu *et al.*, 2001). The present agricultural production practices in Africa are contributing to *Striga* infestation because they depend on the available natural soil nutrients which are already low (Gacheru and Rao, 2001). The most critical factor in *Striga* development is low soil fertility especially nitrogen deficiency. Soil fertility restoration depends on the inputs of nutrients either by mineral or organic fertilizers (Tarawali *et al.*, 2004). Because the sandy soils of the semi arid areas of Tanzania are prone to leaching of these nutrients (Pierce *et al.* 2003), integrated use of organic and inorganic fertilizers is necessary. The nutrients contained in organic manures are released more slowly and stored for a longer time in the soil than inorganic fertilizer nutrients, thereby ensuring a long residue effect (Kamara *et al.*, 2007)

Various studies and field trials have found that *Striga* infestation decreases with integrated use of organic manure and inorganic fertilizers (Sherif and Parker, 1988; Ransom and Odhiambo, 1994; Odhiambo and Ransom, 1997; Elisaba *et al.* 2000; Kayeke *et al.*, 2007; Avav *et al.*, 2009). However, there are still limited scientific studies on the underlying effect of integrated fertility management on *Striga* reproduction. Kayeke *et al.* (2007) reported that application of green manure and urea reduced the number of *Striga* plants by 100%. Elisaba *et al.* (2000) found that application of manure or inorganic fertilizers alone significantly increased *Striga* emergence in maize and sorghum. However, a combination of 40 kg N/ha inorganic fertilizer and manure at all rates reduced *Striga* emergence.

*Striga* produces a large amount of seeds and spreads quickly. Once a field is infested, *Striga* seed banks can remain in place for several years. As the seed bank builds up, infestation by *Striga* becomes worse in each succeeding year (Ishikawa-Goto and Tsuyuzaki, 2004). Therefore, prevention of *Striga* seed production is one of the key elements considered in the management of this difficult to control weed, this study was undertaken to determine the optimum combination of farmyard manure and urea for *Striga* reproduction control and improvement of sorghum grain yield. This could contribute to the knowledge base of *Striga* control for sustainable crop production and wellbeing of people whose livelihoods are agriculture based.

**5.3 Materials and methods**

**5.3.1 Description of experimental sites**

A study was conducted in two locations in semi arid areas of Tanzania, at Hombolo and Melela during the cropping season of January, 2010/2011. Hombolo is located at $05^0$58'S latitude and $35^0$57'E longitude with altitude of 1070 m above sea level. It has an annual mean maximum temperature of $30^0$C and mean annual precipitation ranging from 400 to 750 mm. The soil is sandy with an average pH of 5.4. Melela is located at $06^0$55' S latitude and $37^0$25'E longitude with altitude of 490 m above sea level. The site receives a mean annual rainfall of 750 mm and has a mean maximum temperature of $32^0$C. The soils in the region are either sandy clay, mbuga and alluvial with an average pH of 6.5 (Msanya *et al*., 2003). Fig 5.1: shows the rainfall data for the two sites. Before farmyard manure was applied into the experimental field, manure samples were analyzed for pH, N, P and organic carbon at Sokoine University of Agriculture Soil Laboratory (Table 5.1).

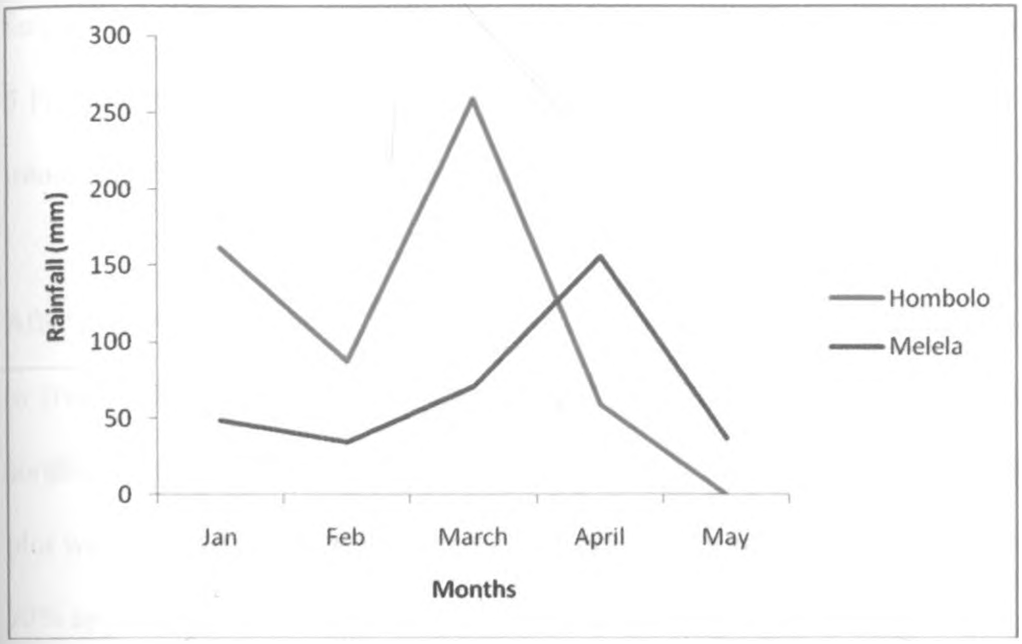


**Fig. 5.1:** Rainfall at Hombolo and Melela during the cropping season in 2010/2011

**Table 5.1:** The pH, organic carbon, N and P content of farmyard manure used in the study

| | | | | Nutrient composition | |
|---|---|---|---|---|---|
| Exp. site | Type of manure | pH | OC (%) | N (%) | P (mg/kg) |
| Hombolo | Farmyard manure | 6.7 | 12.63 | 0.84 | 0.16 |
| Melela | Farmyard manure | 7.3 | 12.14 | 0.63 | 0.29 |

*OC = organic carbon

### 5.3.2 Experimental design and treatments

A 4 x 4 factorial experiment was laid out in a randomized complete block design in fields naturally infested with *Striga asiatica* (Plate 5.1). The treatments composed of urea at 0, 25, 50 and 60 kg N/ha and farmyard manure at 0, 2.98, 5.95 and 7.14 t/ha equivalent to 0, 25, 50, 60 kg N/ha respectively at Hombolo and 0, 3.97, 7.94 and 9.52 (equivalent to 0, 25, 50 and 60 kg N/ha respectively) at Melela. All treatments were replicated three times. The different rates of farmyard manure used were determined based on the analysis of the farmyard manure (Table 5.1). Farmyard manure was uniformly broadcast onto the plots and then thoroughly incorporated into the surface soil (0-20 cm) three weeks before planting sorghum.

After three weeks, sorghum seed (variety Macia) was planted at a spacing of 0.8 m x 0.3 m. Four to five seeds were planted in each hole and then thinned to two plants/hole two weeks after sorghum emergence. The plot size was 3.4 m x 5 m. Four rows with twelve sorghum plants per plot were planted. Thirty percent of mineral N fertilizer was applied at sowing and the remaining 70% applied four weeks after crop emergence. The sorghum plants were left to grow to maturity.

**Plate 5.1**: General view of the field layout of the experiment at Hombolo in 2010/2011 season

### 5.3.3 Crop management and data collection

Sorghum, variety Macia was planted in a field naturally infested with *Striga asiatica* at Hombolo and Melela study sites. During the active growing period all agronomic practices were performed. Experimental plots were kept free of weeds other than *Striga asiatica* using hand hoe and hand pulling methods. At 4 WAP, endosulfan was applied at a rate of 350 g a.i/ha to control stem borers and other insects pests. Bird scarers were employed to prevent birds from attacking the crop at panicle initiation to harvest.

*Determination of Striga growth reproduction parameters*

*Striga* plants were counted every two weeks in each experimental plot. To determine *Striga* reproduction per plant, 10 mature but unopened, green capsules were randomly selected from five *Striga* plants randomly harvested from each plot. The capsules were dried separately, weighed and deducted by 10% of the weight as a correction factor for unremovable trash. The average weight per capsule was divided by $5 \times 10^{-6}$ (average *Striga* seed weight, Berner *et al.* 1997) to get an estimate of the number of seeds per capsule. The number of seeds per capsule was multiplied by the total number of capsules per plant to estimate fecundity (seed production per *Striga* plant). Total dry weight of *Striga* plants per $m^2$ was determined after air-drying the harvested *Striga* plants to constant weight.

*Determination sorghum growth parameters*

At sorghum maturity, panicles were harvested from a net plot area of 4 $m^2$ (from two middle rows) and air dried for two weeks, then threshed and grain yield determined at approximately 14% grain moisture content. Above-ground sorghum biomass was determined by harvesting sorghum plants at ground level. The plants were air-dried for two weeks (until constant weight was attained) and weight was determined.

*Determination of soil moisture content*

Soil moisture level was estimated at flowering and grain maturity stages. Soil moisture content was determined using bulk density method. Bulk density measurements were done using bulk density core sampler as described by Blake (1965). Undisturbed core (5.7cm diameter, 5.2cm high) samples from 0- 20 cm depth were collected from the profiles dug in each of the experimental plot where different fertilizers were applied. Soon after taking the cores, they were taken to the laboratory and their weights were taken. The cores were then placed in an oven at 105°C and dried until constant weight was attained. Then the bulk density and soil moisture content was calculated as:

$$\text{Bulk Density} = \frac{\text{Oven dry weight of soil (g)}}{\text{Volume of soil (cm}^3\text{)}}$$

$$\text{\% Moisture (volume basis)} = 100 \times \frac{\text{(moist soil weight (g) - oven dry soil weight (g))}}{\text{Soil volume (cm}^3\text{)}}$$

*Determination of soil chemical characteristics*

Soils were sampled at 0 – 20 cm depth before and at four weeks after fertilizer application using a 5 cm diameter auger. Prior to planting, the surface soil samples of the experimental area were collected from five points along a diagonal. The soil samples were bulked to form a composite sample. At 4 WAP, composite samples were collected from each plot by randomly sampling three points within the plot. The soil pH was measured in water and in 1M KCl at the ratio 1/2.5

soil-water. Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). Kjeldahl method (Bremner and Mulvaney, 1982) was employed to determine total nitrogen. Phosphorus was extracted by Bray and Kurtz method (Bray and Kurtz, 1945). Exchangeable bases were extracted by saturating soil with neutral 1M $NH_4O$ (Thomas, 1982). The bases $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ displaced by $NH^{4+}$ were measured by atomic absorption spectrophotometer (Thomas, 1982). The Atomic Absorption Spectrophotometer (AAS) method was used to determine zinc and copper (AOAC, 1995).

### 5.3.4 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat statistical software, 12th edition package. Fecundity was calculated as the number of seeds produced per mature plant (Van Mourik, 2007). The xlSTATA software was used for regression analysis of the *Striga* numbers, biomass and sorghum grain and biomass yield on fertilizers. Principal component analysis was performed before a regression analysis for sorghum yield, to study and visualize the correlations between variables to be able to limit the number of variables to be measured in regression. Prior to analysis, *Striga* counts (number/$m^2$) were subjected to square root $(x + 0.5)^{1/2}$ transformation to meet the assumption of the ANOVA, where x was the original observation (Gomez and Gomez, 1984). The means were compared using the least significant difference (LSD) test at 5% probability level.

The following regression model was used:

$$y = \propto + \beta 1X1 + \beta 2X2 + \cdots + \beta n + Xn + \epsilon$$

where $\propto = constant, \beta 1 = Organic\ manure, \beta 2 = Urea, \epsilon = an\ error\ term$

### 5.3.5 Economic analysis

Cost benefit ratio was calculated using methodologies developed by CIMMYT (1988). During the period of this experiment, the farm gate price of sorghum was Tanzania shillings (Tsh) 300/kg, resulting in Tsh 300,000/ton. The cost of fertilizer (urea) was Tsh 900/kg, amounting to Tsh 47,700, Tsh 96,561, and Tsh 115,920/ha at a rate of 25, 50, 60 kg N/ha respectively. The cost of farmyard manure was Tsh 50,000/ton amounting to Tsh 169000, Tsh 338000, and Tsh 406000/ha at a rate of 3.38, 6.76, 8.12 t/ha respectively. The cost of improved seeds was Tsh 3000/kg, resulting in Tsh 22,500/ha. At farm level, the cost of applying fertilizers was Tsh 57,600/ha. The average cost of harvesting sorghum was Tsh 80 per kg.

*The partial budget*

It is a method of organizing experimental data and information about the costs and benefit of various alternative treatments. The partial budget includes the adjusted yield and the gross field benefits (based on the field price of the crop). It is also includes all the costs that vary from each treatment.

*Adjusted yields*

It is the average yield adjusted downward by certain percentage to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. Research has demonstrated that farmers using the same technologies obtain lower yields than those obtained by the researchers. Therefore, yields are adjusted downwards by a certain percent. As a general rule, total adjustments between 5 to 30% are appropriate (CIMMYT, 1988). This is because among other factors, the methods of field management are more precise than those of farmers.

The yields estimated from the small plots often overestimate the yields of an entire field because of errors in the measurement of the harvested area. In addition, small plots tend to be more uniform than large fields. In most cases, farmers' harvesting methods may lead to heavier losses than researchers' harvesting methods. From this study, 10% adjustment was used due to management, 5% due to plot size and 5% due to harvesting differences. Thus, the total yield adjustment used in this experiment was 20%.

*Gross field benefit*

It is the values of the adjusted yield for each treatment. It is determined by multiplying the field price by the adjusted yield. The field price of a crop is the price that farmers receive in the field.

*Variable total costs*

Variable total costs are the costs (per hectare) of purchased inputs and machinery that vary between experimental treatments. The total costs that varied for each treatment were calculated as the sum of the individual costs that varied.

*Net benefit*

Net benefit is defined as total benefit net of total costs. Net benefit was determined by subtracting the variable total costs from the gross benefits for each treatment.

*Dominance analysis*

It is the arrangement of treatments in order of ascending variable costs, with corresponding net benefits. Dominance analysis was carried out by first listing the treatments in order of increasing variable costs. Any treatment that has net benefits that are less than or equal to those of a treatment with lower variable costs is dominated (CYMMIT, 1988). Thus, no farmer would choose treatment that has high variable costs with lower benefit. Such treatment is called dominated treatment and is marked “D”.

*Marginal rate of return*

It is a characteristic of the change from one treatment (practice) to another. It indicates what farmers can expect to gain, on the average in return for their investment when they decide to change from one practice to another. Marginal rate of return was determined as the marginal net benefit divided by the marginal costs and expressed in a percentage (CIMMYT, 1988).

*Where:*

*Marginal net benefit*

Marginal cost is a term used to describe the change in net benefit of production resulting from the addition of one item. It determines what the increase in total benefits would be if one more unit of the control variable was added (CIMMYT, 1988).

*Marginal net cost*

Marginal cost is a term used to describe the change in total costs of production resulting from the addition of one item. It determines what the increase in total cost would be if one more unit of the control variable was added (CIMMYT, 1988).

## 5.4 RESULTS

### 5.4.1 Effect of combined farmyard manure and urea on *Striga* performance and reproduction

Application of farmyard manure, urea and their interaction had significant ($P \leq 0.05$) effects on *Striga* numbers/$m^2$ at Hombolo (Table 5.2). At 0 kg N/ha FYM, none of the urea treatments had significant effect on *Striga* number/$m^2$. At 25 kg N/ha FYM, only application of 50 and 60 kg N/ha urea reduced the *Striga* numbers. At 50 and 60 kg N/ha FYM, application of urea at all rates significantly reduced *Striga* numbers. At 0 and 25 kg N/ha urea, application of 25 kg N/ha FYM significantly increased *Striga* numbers. At Melela, application of 25 kg N/ha FYM had significantly higher number of *Striga* plants than the control and other FYM treatments. Application of 50 kg N/ha and 60 kg N/ha FYM had no effect on *Striga* numbers. The zero urea treatment had the highest *Striga* numbers while 25 kg N/ha urea treatment had significantly higher *Striga* numbers than 50 and 60 kg N/ha urea treatments. At Melela, farmyard manure and urea had significant effects on *Striga* numbers while their interaction had no effect. Application of 25 kg N/ha farmyard manure significantly increased the number of *Striga* plants/$m^2$ relative to the control while the higher FYM rates had no effect.

**Table 5.2:** Effect of varying rates of urea and farmyard manure on maximum *Striga* numbers/m$^2$ at Hombolo and Melela study sites in 2010/2011 season

| | Hombolo | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 5.21 | 4.58 | 4.26 | 4.00 | 4.51 |
| 25 | 6.65 | 6.75 | 4.54 | 4.27 | 5.55 |
| 50 | 5.77 | 3.89 | 4.07 | 4.10 | 4.46 |
| 60 | 5.71 | 3.10 | 4.28 | 2.74 | 3.96 |
| Mean | 5.84 | 4.58 | 4.29 | 3.78 | 4.62 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.65 | | | | |
| Urea | 0.65 | | | | |
| FYM x Urea | 1.30 | | | | |
| | Melela | | | | |
| 0 | 6.60 | 4.54 | 3.97 | 2.93 | 4.51 |
| 25 | 7.70 | 6.72 | 4.41 | 4.27 | 5.77 |
| 50 | 6.12 | 4.03 | 4.07 | 4.08 | 4.57 |
| 60 | 5.92 | 4.37 | 4.47 | 3.36 | 4.53 |
| Mean | 6.58 | 4.91 | 4.23 | 3.66 | 4.85 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.64 | | | | |
| Urea | 0.64 | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

There was no significant effect ($P \leq 0.05$) of farmyard manure and farmyard manure by urea interaction on *Striga* biomass in both sites (Table 5.3). In both sites, application of 60 kg N/ha urea significantly reduced the *Striga* biomass relative to the control while the other rates did not have significant effect.

**Table 5.3:** Effect of varying rates of urea and farmyard manure on *Striga* biomass (g/m$^2$) at Hombolo and Melela study sites in 2010/2011 season

| | Hombolo | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 15.80 | 12.10 | 13.20 | 6.50 | 11.90 |
| 25 | 32.80 | 11.40 | 11.00 | 8.50 | 15.90 |
| 50 | 11.00 | 10.60 | 13.10 | 8.30 | 10.70 |
| 60 | 11.70 | 10.80 | 12.20 | 7.10 | 10.40 |
| Mean | 17.80 | 11.20 | 12.40 | 7.60 | 12.20 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | 7.15 | | | | |
| FYM x Urea | NS | | | | |
| | Melela | | | | |
| 0 | 24.50 | 14.10 | 16.90 | 10.20 | 16.40 |
| 25 | 28.80 | 20.10 | 10.50 | 13.20 | 18.10 |
| 50 | 12.90 | 12.40 | 14.80 | 10.40 | 12.60 |
| 60 | 13.50 | 12.70 | 13.80 | 8.80 | 12.20 |
| Mean | 19.90 | 14.80 | 14.00 | 10.70 | 14.80 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | 5.91 | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

Farmyard manure, urea and farmyard manure x urea significantly ($P \leq 0.05$) affected the number of *Striga* capsules per plant in both sites (Table 5.4). At zero level of farmyard manure, application of 60 kg N/ha urea significantly reduced the number of capsules/plant in both sites (Table 5.4). At 25 kg N/ha (FYM), application of 50 kg N/ha urea and above significantly reduced the number of capsules/plant in both sites. At 50 kg N/ha (FYM), only application of 25 kg N/ha urea significantly reduced the number of capsules/plant at Hombolo while none of the urea treatments reduced the number of capsules at Melela. At 25 kg N/ha urea, application of 50 and 60 kg N/ha FYM at Hombolo and application of 50 kg N/ha at Melela significantly reduced the number of capsules/plant, respectively. At 60 kg N/ha FYM, application of 25 kg N/ha urea and above at Hombolo and only application of 60 kg N/ha urea at Melela significantly reduced the number of capsules/plant. At zero level of urea, only 50 kg N/ha FYM significantly reduced the number of capsules/plant at Hombolo while 50 and 60 kg N/ha FYM significantly reduced the number of capsules at Melela. At 50 kg N/ha urea, application of 25 kg N/ha FYM and above significantly reduced the number of capsules/plant at both sites.

**Table 5.4:** Effect of varying rates of urea and farmyard manure on the number of capsules/plant at Hombolo and Melela study sites in 2010/2011

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 70.10 | 69.40 | 81.00 | 42.30 | 65.70 |
| 25 | 78.50 | 56.00 | 47.70 | 48.00 | 57.60 |
| 50 | 51.90 | 34.60 | 41.10 | 41.10 | 42.20 |
| 60 | 74.80 | 46.40 | 48.30 | 39.90 | 52.40 |
| Mean | 68.80 | 51.60 | 54.50 | 42.80 | 54.40 |
| LSD (≤ 5%) | | | | | |
| FYM | 8.46 | | | | |
| Urea | 8.46 | | | | |
| FYM x Urea | 16.91 | | | | |
| | **Melela** | | | | |
| 0 | 73.40 | 66.10 | 67.70 | 35.7 | 60.70 |
| 25 | 88.50 | 56.00 | 44.30 | 47.80 | 59.20 |
| 50 | 45.30 | 44.60 | 37.70 | 44.50 | 43.00 |
| 60 | 54.80 | 53.10 | 45.30 | 38.60 | 47.90 |
| Mean | 65.50 | 54.90 | 48.70 | 41.60 | 52.70 |
| LSD (≤ 5%) | | | | | |
| FYM | 7.73 | | | | |
| Urea | 7.73 | | | | |
| FYM x Urea | 15.45 | | | | |

*equiv = equivalent; FYM = farmyard manure

Farmyard manure, urea and farmyard manure x urea significantly ($P \leq 0.05$) affected the *Striga* fecundity in both sites (Table 5.5). At 25 kg N/ha FYM, application of 25 kg N/ha urea and above significantly reduced the *Striga* fecundity at Hombolo and Melela. At 50 and 60 kg N/ha

FYM, urea application had no effect on *Striga* fecundity in both Hombolo and Melela. At 0 kg N/ha urea, application of 50 and 60 kg N/ha FYM significantly reduced the *Striga* fecundity at both sites. However, application of 25 kg N/ha FYM significantly increased fecundity at Melela. At 25 kg N/ha urea, application of 25 kg N/ha FYM and above reduced the fecundity at Hombolo while only 50 and 60 kg N/ha FYM reduced *Striga* fecundity at Melela. At 50 kg N/ha urea, application of 25 kg N/ha FYM and above significantly reduced the *Striga* fecundity in both sites (Table 5.5).

**Table 5.5:** Effect of varying rates of urea and farmyard manure on the *Striga* fecundity (seeds/plant) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 37556 | 37198 | 43416 | 15544 | 33429 |
| 25 | 42094 | 24674 | 25549 | 25911 | 29557 |
| 50 | 24272 | 18546 | 22012 | 22212 | 21760 |
| 60 | 29373 | 14159 | 25404 | 21404 | 22702 |
| Mean | 33324 | 23644 | 29212 | 21268 | 26862 |
| LSD (≤ 5%) | | | | | |
| FYM | 3329 | | | | |
| Urea | 3329 | | | | |
| FYM x Urea | 6658.1 | | | | |
| | **Melela** | | | | |
| 0 | 39636 | 35676 | 36540 | 19260 | 32778 |
| 25 | 47808 | 30258 | 23940 | 25821 | 31957 |
| 50 | 24813 | 24084 | 20376 | 24012 | 23321 |
| 60 | 29232 | 38665 | 24444 | 20844 | 25796 |
| Mean | 35372 | 29451 | 26325 | 22484 | 28463 |
| LSD (≤ 5%) | | | | | |
| FYM | 4201.6 | | | | |
| Urea | 4201.6 | | | | |
| FYM x Urea | 8403.3 | | | | |

equiv = equivalent; FYM = farmyard manure

The regression analysis showed that there were significant ($P \leq 0.05$) reductions in *Striga* biomass and numbers when urea was used alone at Hombolo (Table 5.6). However, at Melela both fertilizers and their interaction had significant effects on *Striga* biomass and numbers. An increase in a unit of FYM and urea reduced *Striga* biomass by 0.2006 and 0.2502 units, respectively, at Melela. In contrast, *Striga* numbers reduced by 0.0265 and 0.0614 units at Hombolo and Melela, respectively, if urea increased by one unit. The variances accounted for by the explanatory terms for *Striga* biomass and numbers were 10.9 and 34.3% respectively at Hombolo and 24.7 and 54.8%, respectively, at Melela. Regression analysis showed that there was significant reduction in the number of capsules/plant when farmyard manure and urea were applied. The number of capsules/*Striga* plant reduced by 0.499 and 0.590 at Melela when both farmyard manure and urea increased by one unit, respectively, when other factors were held constant. The variances accounted for by the explanatory terms for number of capsules/plant were 37.8% and 47.7% at Hombolo and Melela respectively (Table 5.6).

The regression analysis showed that there were significant ($P \leq 0.05$) reductions in *Striga* biomass and numbers when urea was used alone at Hombolo (Table 5.6). However, at Melela both fertilizers and their interaction had significant effects on *Striga* biomass and numbers. An increase in a unit of FYM and urea reduced *Striga* biomass by 0.2006 and 0.2502 units, respectively, at Melela. In contrast, *Striga* numbers reduced by 0.0265 and 0.0614 units at Hombolo and Melela, respectively, if urea increased by one unit. The variances accounted for by the explanatory terms for *Striga* biomass and numbers were 10.9 and 34.3% respectively at Hombolo and 24.7 and 54.8%, respectively, at Melela. Regression analysis showed that there was significant reduction in the number of capsules/plant when farmyard manure and urea were applied. The number of capsules/*Striga* plant reduced by 0.499 and 0.590 at Melela when both farmyard manure and urea increased by one unit, respectively, when other factors were held constant. The variances accounted for by the explanatory terms for number of capsules/plant were 37.8% and 47.7% at Hombolo and Melela respectively (Table 5.6).

**Table 5.6:** Summary of the ANOVA table for the regression of *Striga* performance on applied nitrogen at Hombolo and Melela study sites in 2010/2011 season

| Parameter | Explanatory term | Hombolo | | Melela | |
|---|---|---|---|---|---|
| | | Estimated value | % variance explained | Estimated value | % variance explained |
| *Striga* biomass | Constant | 21.35* | | 26.19* | |
| | FYM | -0.1312 NS | 10.9 | -0.2006* | 24.7 |
| | Urea | -0.2266* | | -0.2502* | |
| | FYM.Urea | 0.00261 NS | | 0.00339** | |
| *Striga* max. numbers | Constant | 5.898* | | 7.067* | |
| | FYM | -0.0064 NS | 34.3 | -0.0196 NS | 54.8 |
| | Urea | -0.0265* | | -0.0614* | |
| | FYM.Urea | -0.000146 NS | | -0.00045** | |
| Number of capsules/plant | Constant | 75.23* | | 82.12* | |
| | FYM | -0.263** | 37.8 | -0.499* | 47.7 |
| | Urea | -0.311* | | -0.590* | |
| | FYM.Urea | 0.00123 NS | | -0.00648* | |

*Regression is significant at the $P \leq 0.05$ level; **Regression is significant at the $P \leq 0.1$ level
FYM = Farmyard manure, Max. = maximum number of *Striga* plants; NS = mean values not significant different

**5.4.2 Effect of combined farmyard manure and urea on sorghum biomass and grain yield**

There were significant ($P \leq 0.05$) urea, farmyard manure and farmyard manure by urea interaction effects on sorghum biomass at both sites (Table 5.7). At 0 kg N/ha FYM, application of 50 and 60 kg N/ha urea significantly increased sorghum biomass while application of 25 kg N/ha urea had no effect on sorghum biomass in both sites. At 25 kg N/ha FYM, application of 25 kg N/ha urea and above significantly increased sorghum biomass at Hombolo while application of 50 kg N/ha urea and above increased sorghum biomass at Melela. At 50 kg N/ha FYM, application of 25 kg N/ha urea and above significantly increased sorghum biomass in both sites.

At 60 kg N/ha FYM, application of 25 kg N/ha and above urea significantly increased sorghum biomass in both sites. At 0 kg N/ha urea, application of 50 and 60 kg N/ha FYM had significantly higher sorghum biomass than application of 25 kg N/ha FYM and the control in both sites (Table 5.7).

**Table 5.7:** Effect of varying rates of urea and farmyard manure on sorghum biomass (t/ha) at Hombolo and Melela study sites in 2010/2011 season

| | Hombolo | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 3.46 | 4.34 | 5.29 | 6.23 | 4.83 |
| 25 | 3.60 | 5.08 | 6.81 | 7.16 | 5.66 |
| 50 | 5.99 | 5.51 | 6.85 | 6.86 | 6.30 |
| 60 | 6.01 | 6.07 | 6.19 | 8.41 | 6.67 |
| Mean | 4.76 | 5.25 | 6.29 | 7.16 | 5.87 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.59 | | | | |
| Urea | 0.59 | | | | |
| FYM x Urea | 1.17 | | | | |
| | Melela | | | | |
| 0 | 4.30 | 5.30 | 6.37 | 7.44 | 5.86 |
| 25 | 4.08 | 5.38 | 7.35 | 8.12 | 6.23 |
| 50 | 6.79 | 6.24 | 8.91 | 7.78 | 7.43 |
| 60 | 7.19 | 7.27 | 7.40 | 9.81 | 7.91 |
| Mean | 5.59 | 6.05 | 7.51 | 8.29 | 6.86 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.70 | | | | |
| Urea | 0.70 | | | | |
| FYM x Urea | 1.41 | | | | |

*equiv = equivalent; FYM = farmyard manure

Sorghum grain yield ranged from 1.95 t/ha (control) to 5.72 t/ha (60 kg N/ha urea with 60 kg N/ha FYM) at Hombolo and 2.0 (control) to 7.56 t/ha (60 kg N/ha urea with 60 kg N/ha FYM) at Melela (Table 5.8). Farmyard manure and urea significantly affected sorghum grain yield in both sites while farmyard manure x urea interaction had no effect on sorghum grain yield in both sites (Table 5.8). Application of 25 kg N/ha urea and above significantly increased sorghum grain yield at Hombolo while at Melela only application of 50 and 60 kg N/ha urea significantly increased sorghum grain yield. At both sites, application of 50 and 60 kg N/ha urea had significantly higher yield than application of 25 kg N/ha urea. Application of 25 kg N/ha FYM and above significantly increased sorghum grain yield at Hombolo while only application of 50 and 60 kg N/ha FYM significantly increased sorghum grain yield at Melela. In both sites, application of 50 and 60 kg N/ha FYM had significantly higher grain yield than application of 25 kg N/ha (Table 5.8).

**Table 5.8:** Effect of varying rates of urea and farmyard manure on sorghum grain yield (t/ha) at Hombolo and Melela study sites in 2010/2011 season

| | | | **Hombolo** | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 1.95 | 2.38 | 3.78 | 4.15 | 3.07 |
| 25 | 2.55 | 3.55 | 5.27 | 5.55 | 4.23 |
| 50 | 3.72 | 4.78 | 5.32 | 5.17 | 4.75 |
| 60 | 4.28 | 4.60 | 5.23 | 5.72 | 4.96 |
| Mean | 3.13 | 3.83 | 4.90 | 5.15 | 4.25 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.51 | | | | |
| Urea | 0.51 | | | | |
| FYM x Urea | NS | | | | |
| | | **Melela** | | | |
| 0 | 2.00 | 3.33 | 4.26 | 4.29 | 3.49 |
| 25 | 3.00 | 3.00 | 4.80 | 4.66 | 3.86 |
| 50 | 4.41 | 4.70 | 6.17 | 6.33 | 5.40 |
| 60 | 4.72 | 5.52 | 5.56 | 7.56 | 5.82 |
| Mean | 3.53 | 4.14 | 5.17 | 5.73 | 4.64 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.79 | | | | |
| Urea | 0.79 | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

### 5.4.3 Interaction effect of *Striga* numbers and combined farmyard manure and urea on sorghum grain yield

Principal component analysis on sorghum yield led to selection of *Striga* numbers that contributed 64% of the commulative yield variability (Fig 5.4) since the remaining variables were positively correlated with the selected variables (Table 5.9).

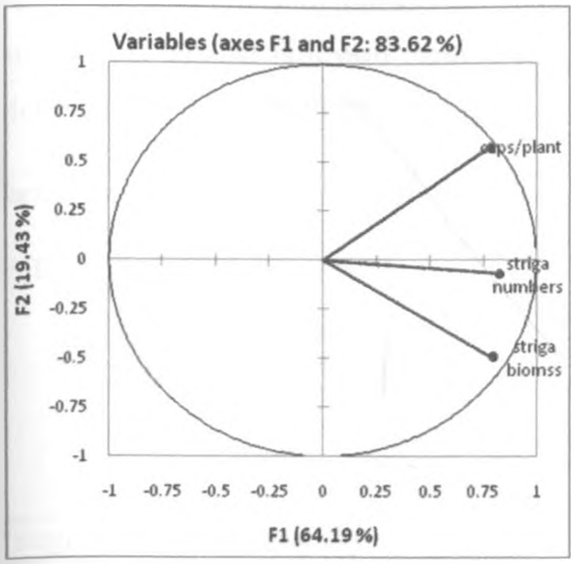


**Fig 5.2:** Discriminate analysis ordination graph showing contribution of *Striga* numbers, biomass and capsules/plant on sorghum yield

*Caps = capsules

**Table 5.9:** Pearson correlation matrix

| Variables | *Striga* numbers | capsules/plant | *Striga* biomass |
|---|---|---|---|
| *Striga* numbers | 1 | | |
| Number of capsules/plant | 0.475 | 1 | |
| *Striga* biomass | 0.494 | 0.418 | 1 |

The regression analysis showed that farmyard manure, urea, *Striga* infestation level and the interaction of manure, urea and *Striga* numbers contributed significantly ($P \leq 0.05$) to the explanation of variation in sorghum grain yield in both experimental sites (Table 5.10).

**Table 5.10:** Summary of the ANOVA table for the regression of interaction effect of *Striga* number and applied farmyard manure and urea on sorghum grain yield across Hombolo and Melela study sites in 2010/2011 season

| Parameter | Explanatory term | Value | Standardized coefficients | $R^2$ |
|---|---|---|---|---|
| Sorghum grain yield | Constant | 1506.426* | | 0.78 |
| | FYM | 36.614* | 0.683 | |
| | Urea | 59.404* | 1.108 | |
| | *Striga* numbers | -26.246* | -0.026 | |
| | FYM*Urea | 0.282** | 0.279 | |
| | FYM**Striga* numbers | 1.086* | 0.093 | |
| | Urea**Striga* numbers | -2.859** | -0.222 | |
| | FYM*Urea**Striga* numbers | -0.014* | -0.054 | |

*Regression is significant at ≤ 0.05 probability level; FYM = farmyard manure
**Regression is significant at ≤ 0.1 probability level

The regression analysis showed that there was high contribution of urea to sorghum yield as explained by high standardized coefficients compared to farmyard manure. An increase in one unit of *Striga* number reduced sorghum yield by 26.246 units when other factors were held constant. When other factors were held constant, sorghum grain yield increases by 59.40 if urea increased by 1 unit, similarly one unit increase in farmyard manure with other factors held constant would increase yield by 36.61units (Table 5.10).

### 5.4.4 Effect of combined farmyard manure and urea on soil physical-chemical characteristics

The initial physical-chemical properties of soils at both sites are presented in Table 5.11.

**Table 5.11:** Initial physical-chemical characteristics of soil at the experimental sites in 2010/2011 season

| Parameter | Hombolo | Level | Melela | Value |
|---|---|---|---|---|
| pH | 5.40 | Strong acidic | 6.50 | Slightly acidic |
| OC (%) | 0.51 | Very low | 2.00 | Medium |
| Total N (%) | 0.07 | Very low | 0.13 | Low |
| Available P (mg/kg) | 7.03 | Medium | 39.75 | High |
| K (mg/kg) | 0.68 | High | 1.37 | High |
| Mg (mg/kg) | 0.65 | Medium | 3.63 | Very high |
| Ca (mg/kg) | 0.79 | Medium | 22.36 | Very high |
| Zn (mg/kg) | 0.39 | Low | 1.51 | Low |
| Cu (mg/kg) | 0.18 | Low* | 1.72 | Low* |

*Refer to the critical values in appendix 2

| Particle size | Hombolo | Melela |
|---|---|---|
| Sand (%) | 72 | 51 |
| Silt (%) | 3 | 14 |
| Clay (%) | 25 | 35 |
| Textural class | Sandy clay | Sandy clay |

At the onset of the trials, total soil N and organic carbon (OC) contents varied considerably between sites (Table 5.11). Available phosphorus (P) was medium at Hombolo and high at Melela, potassium (K) was high in both sites. Soil pH was strongly acidic at Hombolo and slightly acidic at Melela. Other exchangeable bases (Ca, Mg) and micronutrients (Zn Fe, Cu) were medium to low at both sites.

Urea, farmyard manure and their interaction significantly affected the soil nitrogen at Hombolo but had no effect at Melela (Table 5.12). Means for the soil nitrogen ranged from 0.07 to 0.11 at Hombolo and 0.13 to 0.16 at Melela. At all levels of FYM, urea application had no effect on soil nitrogen at Melela. At 0 and 25 kg N/ha urea, FYM application at all levels significantly increased N content while at 50 and 60 kg N/ha urea, FYM application had no effect at Hombolo.

**Table 5.12:** Effect of varying rates of urea and farmyard manure on soil nitrogen (%) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 0.07 | 0.07 | 0.07 | 0.08 | 0.07 |
| 25 | 0.09 | 0.10 | 0.08 | 0.10 | 0.09 |
| 50 | 0.11 | 0.09 | 0.08 | 0.08 | 0.09 |
| 60 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 |
| Mean | 0.09 | 0.09 | 0.08 | 0.09 | |
| LSD (≤ 5%) | | | | | |
| FYM | 0.01 | | | | |
| Urea | 0.01 | | | | |
| FYM x Urea | 0.02 | | | | |
| | **Melela** | | | | |
| 0 | 0.13 | 0.14 | 0.14 | 0.13 | 0.14 |
| 25 | 0.14 | 0.14 | 0.14 | 0.16 | 0.15 |
| 50 | 0.17 | 0.15 | 0.14 | 0.14 | 0.15 |
| 60 | 0.15 | 0.16 | 0.15 | 0.16 | 0.15 |
| Mean | 0.15 | 0.15 | 0.14 | 0.15 | 0.15 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

In both sites, farmyard manure significantly affected the soil organic carbon while urea application had no effect (Table 5.13). At Hombolo, only application of 60 kg N/ha FYM significantly increased soil organic carbon. The interaction between urea and farmyard manure had a significant effect at Melela but not at Hombolo. At 0 kg N/ha FYM, application of 25 kg N/ha urea significantly reduced organic carbon while application of 50 and 60 kg N/ha urea had no effect in both sites. At 25, 50 and 60 kg N/ha FYM, application of urea had no effect on soil organic carbon at Hombolo. Mean soil organic carbon ranged from 0.38 to 0.84% at Hombolo and 1.87 to 2.33% at Melela. At 0 kg N/ha urea, application of 50 and 60 kg N/ha FYM increased soil organic carbon significantly while at 25 kg N/ha urea, application of 25 kg N/ha FYM and above significantly increased soil organic carbon. At 50 kg N/ha urea, no significant differences in soil organic carbon were noted among FYM treatments, while at 60 kg N/ha urea application of 60 kg N/ha had significantly the highest soil organic carbon.

**Table 5.13:** Effect of varying rates of urea and farmyard manure on soil organic carbon (OC %) at Hombolo and Melela study sites in 2010/2011 season

| FYM (kg N/ha equiv) | Urea (kg N/ha) 0 | 25 | 50 | 60 | Mean |
|---|---|---|---|---|---|
| **Hombolo** | | | | | |
| 0 | 0.59 | 0.38 | 0.57 | 0.57 | 0.53 |
| 25 | 0.65 | 0.67 | 0.61 | 0.62 | 0.64 |
| 50 | 0.73 | 0.73 | 0.63 | 0.65 | 0.69 |
| 60 | 0.74 | 0.77 | 0.84 | 0.71 | 0.77 |
| Mean | 0.68 | 0.64 | 0.66 | 0.64 | 0.65 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.16 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| **Melela** | | | | | |
| 0 | 2.08 | 2.07 | 2.06 | 2.06 | 2.07 |
| 25 | 2.07 | 2.16 | 2.11 | 2.10 | 2.11 |
| 50 | 2.29 | 2.22 | 2.14 | 2.12 | 2.19 |
| 60 | 2.23 | 2.26 | 2.20 | 2.33 | 2.26 |
| Mean | 2.17 | 2.13 | 2.13 | 2.15 | 2.15 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.07 | | | | |
| Urea | NS | | | | |
| FYM x Urea | 0.15 | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

The mean soil P was significantly ($P \leq 0.05$) affected by farmyard manure at Hombolo but not at Melela (Table 5.14). Urea application and its interaction with farmyard manure had no effect on soil P in both sites. At Hombolo, farmyard manure treated plots had higher soil P than the control plots. Application of 60 kg N/ha FYM had significantly higher soil P than application of 25 and 50 kg N/ha FYM. The mean P content ranged from 5.78 to 12.05 mg/kg at Hombolo and 37.5 to 43.02 mg/kg at Melela.

**Table 5.14:** Effect of varying rates of urea and farmyard manure on soil phosphorus (mg/kg) at Hombolo and Melela study sites in 2010/2011 season

| | | | | | |
|---|---|---|---|---|---|
| | **Hombolo** | | | | |
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 6.61 | 4.70 | 5.43 | 6.40 | 5.78 |
| 25 | 10.20 | 12.26 | 11.68 | 9.52 | 10.91 |
| 50 | 11.18 | 10.70 | 10.59 | 10.72 | 10.80 |
| 60 | 12.83 | 11.12 | 11.88 | 12.36 | 12.05 |
| Mean | 10.21 | 9.70 | 9.89 | 9.75 | 9.89 |
| LSD (≤ 5%) | | | | | |
| FYM | 1.09 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 38.54 | 36.29 | 38.02 | 37.02 | 37.50 |
| 25 | 41.79 | 41.51 | 41.11 | 41.49 | 41.47 |
| 50 | 42.77 | 42.29 | 42.31 | 42.18 | 42.39 |
| 60 | 44.42 | 42.71 | 42.28 | 42.67 | 43.02 |
| Mean | 41.88 | 40.70 | 40.96 | 40.84 | 41.10 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

In both sites, the mean soil K was significantly ($P \leq 0.05$) increased by farmyard manure application while urea application and its interaction with FYM had no significant effect (Table 5.15). No differences were noted in mean K content among 25, 50 and 60 kg N/ha FYM rates in both sites.

**Table 5.15:** Effect of varying rates of urea and farmyard manure on soil potassium (mg/kg) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 0.83 | 0.70 | 0.93 | 1.21 | 0.92 |
| 25 | 1.09 | 1.39 | 1.27 | 1.37 | 1.28 |
| 50 | 1.27 | 1.03 | 1.21 | 1.29 | 1.20 |
| 60 | 1.30 | 1.34 | 1.38 | 1.33 | 1.34 |
| Mean | 1.12 | 1.11 | 1.20 | 1.30 | 1.18 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.26 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 1.55 | 1.42 | 1.65 | 1.93 | 1.64 |
| 25 | 1.81 | 2.11 | 1.99 | 2.09 | 2.00 |
| 50 | 1.99 | 1.75 | 1.93 | 2.01 | 1.92 |
| 60 | 2.02 | 2.06 | 2.10 | 2.05 | 2.06 |
| Mean | 1.84 | 1.83 | 1.92 | 2.02 | 1.90 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.27 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

In both sites, farmyard manure had a significant effect ($P \leq 0.05$) on soil Mg. Urea and urea x farmyard manure interaction had no effect (Table 5.16). At Hombolo, application of 50 and 60 kg N/ha FYM significantly increased Mg content while application of 25 kg N/ha had no significant effect. Application of 25 kg N/ha FYM and above significantly increased Mg content at Melela. Magnesium content varied from 1.01 to 1.20 mg/kg at Hombolo and 3.88 to 4.18 mg/kg at Melela.

**Table 5.16:** Effect of varying rates of urea and farmyard manure on soil magnesium (mg/kg) at Hombolo and Melela study sites in 2010/2011 season

| | | | | | |
|---|---|---|---|---|---|
| | **Hombolo** | | | | |
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 0.84 | 1.08 | 0.94 | 1.16 | 1.01 |
| 25 | 1.08 | 0.97 | 1.09 | 1.28 | 1.10 |
| 50 | 1.32 | 1.21 | 1.16 | 1.10 | 1.20 |
| 60 | 0.98 | 1.09 | 1.39 | 1.35 | 1.20 |
| Mean | 1.06 | 1.09 | 1.15 | 1.22 | 1.13 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.14 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 3.49 | 3.89 | 4.21 | 3.92 | 3.88 |
| 25 | 4.06 | 4.08 | 4.26 | 4.17 | 4.14 |
| 50 | 3.96 | 4.19 | 4.08 | 4.07 | 4.15 |
| 60 | 4.24 | 4.07 | 4.33 | 4.37 | 4.18 |
| Mean | 3.94 | 4.06 | 4.22 | 4.13 | 4.09 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.23 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

The mean soil calcium content was not significantly ($P \leq 0.05$) affected by FYM and urea application in both sites. Mean calcium content ranged from 3.45 to 4.09 mg/kg at Hombolo and 23.27 to 24.65 mg/kg at Melela (Table 5.17).

**Table 5.17:** Effect of varying rates of urea and farmyard manure on soil calcium (mg/kg) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25.00 | 50 | 60 | Mean |
| 0 | 2.88 | 3.50 | 3.54 | 3.88 | 3.45 |
| 25 | 3.68 | 3.76 | 4.06 | 4.35 | 3.96 |
| 50 | 4.28 | 4.13 | 3.72 | 3.76 | 3.97 |
| 60 | 3.32 | 3.70 | 4.75 | 4.59 | 4.09 |
| Mean | 3.54 | 3.77 | 4.02 | 4.14 | 3.87 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 22.77 | 23.13 | 24.07 | 23.10 | 23.27 |
| 25 | 24.24 | 24.32 | 24.57 | 24.62 | 24.44 |
| 50 | 24.84 | 24.69 | 24.32 | 24.28 | 24.53 |
| 60 | 23.88 | 24.26 | 25.15 | 25.31 | 24.65 |
| Mean | 23.93 | 24.10 | 24.53 | 24.33 | 24.22 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

Farmyard manure and urea significantly affected the soil Zn content in both sites (Table 5.18). The interaction between farmyard manure and urea had no effect on Zn content in both sites. At Hombolo, application of 25 kg N/ha urea and above significantly reduced Zn content relative to the control. At Melela, only application of 60 kg N/ha FYM significantly increased Zn content. Mean Zn content ranged from 0.26 to 0.37 mg/kg at Hombolo and 1.35 to 1.52 mg/kg at Melela.

**Table 5.18:** Effect of varying rates of urea and farmyard manure on soil zinc (mg/kg) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 0.37 | 0.23 | 0.23 | 0.22 | 0.26 |
| 25 | 0.36 | 0.36 | 0.35 | 0.36 | 0.36 |
| 50 | 0.37 | 0.38 | 0.37 | 0.35 | 0.37 |
| 60 | 0.38 | 0.38 | 0.36 | 0.35 | 0.37 |
| Mean | 0.37 | 0.34 | 0.33 | 0.32 | 0.34 |
| LSD ($\leq$ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | 0.06 | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 1.39 | 1.36 | 1.33 | 1.34 | 1.35 |
| 25 | 1.48 | 1.45 | 1.37 | 1.37 | 1.42 |
| 50 | 1.50 | 1.49 | 1.50 | 1.45 | 1.49 |
| 60 | 1.62 | 1.49 | 1.46 | 1.50 | 1.52 |
| Mean | 1.50 | 1.45 | 1.42 | 1.42 | 1.44 |
| LSD ($\leq$ 5%) | | | | | |
| FYM | 0.11 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

Farmyard manure and farmyard manure by urea interaction caused significant ($P \leq 0.05$) changes in soil copper at Hombolo but urea application had no effect (Table 5.19). Application of urea had no significant effect on Cu content when combined with 0 kg N/ha and 25 kg N/ha FYM. Application of 60 kg N/ha FYM significantly increased Cu content at most urea levels. Application of urea and farmyard manure did not significantly change soil copper at Melela. The mean Cu content ranged from 0.22 to 0.30 mg/kg at Hombolo and 1.75 to 1.83 mg/kg at Melela (Table 5.19).

**Table 5.19:** Effect of varying rates of urea and farmyard manure on soil copper (mg/kg) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 0.21 | 0.23 | 0.23 | 0.23 | 0.22 |
| 25 | 0.23 | 0.23 | 0.25 | 0.23 | 0.23 |
| 50 | 0.33 | 0.23 | 0.27 | 0.23 | 0.26 |
| 60 | 0.28 | 0.35 | 0.25 | 0.33 | 0.30 |
| Mean | 0.26 | 0.26 | 0.25 | 0.25 | 0.26 |
| LSD (≤ 5%) | | | | | |
| FYM | 0.01 | | | | |
| Urea | NS | | | | |
| FYM x Urea | 0.03 | | | | |
| | **Melela** | | | | |
| 0 | 1.75 | 1.74 | 1.75 | 1.75 | 1.75 |
| 25 | 1.75 | 1.74 | 1.77 | 1.80 | 1.76 |
| 50 | 1.86 | 1.75 | 1.76 | 1.80 | 1.79 |
| 60 | 1.81 | 1.89 | 1.86 | 1.75 | 1.83 |
| Mean | 1.79 | 1.78 | 1.78 | 1.78 | 1.78 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

The soil pH levels at Hombolo and Melela are presented in Table 5.20. Farmyard manure and urea applications did not significantly change the soil pH in both sites. Soil pH ranged from 6.57 to 6.76 at Hombolo and 6.57 to 6.76 at Melela.

**Table 5.20:** Effect of varying rates of urea and farmyard manure on soil pH at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 6.68 | 6.69 | 6.39 | 6.51 | 6.57 |
| 25 | 6.71 | 6.78 | 6.93 | 6.76 | 6.79 |
| 50 | 6.87 | 6.80 | 6.64 | 6.58 | 6.72 |
| 60 | 6.73 | 6.63 | 6.88 | 6.78 | 6.76 |
| Mean | 6.75 | 6.72 | 6.71 | 6.66 | 6.71 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 6.70 | 6.71 | 6.53 | 6.41 | 6.57 |
| 25 | 6.73 | 6.80 | 6.78 | 6.95 | 6.79 |
| 50 | 6.89 | 6.82 | 6.60 | 6.69 | 6.72 |
| 60 | 6.75 | 6.65 | 6.80 | 6.90 | 6.76 |
| Mean | 6.75 | 6.72 | 6.71 | 6.66 | 6.71 |
| LSD (≤ 5%) | | | | | |
| FYM | NS | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different

Farmyard manure application significantly ($P \leq 0.05$) affected the soil moisture content in both sites while urea application had no effect (Table 5.21). Application of farmyard manure significantly improved soil moisture retention at 0 and 60 kg N/ha urea but had no effect at 25 and 50 kg N/ha urea at Hombolo. At Melela, significant increases in soil moisture contents were recorded when 50 and 60 kg N/ha FYM were applied. Soil moisture content varied from 11.37 to 13.85% at Hombolo and 11.17 to 15% at Melela.

**Table 5.21:** Effect of varying rates of urea and farmyard manure on soil moisture (Volume %) at Hombolo and Melela study sites in 2010/2011 season

| | **Hombolo** | | | | |
|---|---|---|---|---|---|
| FYM | Urea (kg N/ha) | | | | |
| (kg N/ha equiv) | 0 | 25 | 50 | 60 | Mean |
| 0 | 8.97 | 12.69 | 13.42 | 10.42 | 11.37 |
| 25 | 11.11 | 10.59 | 10.98 | 12.72 | 11.35 |
| 50 | 14.82 | 10.67 | 10.93 | 12.68 | 12.27 |
| 60 | 14.92 | 12.78 | 13.59 | 14.11 | 13.85 |
| Mean | 12.45 | 11.68 | 12.23 | 12.48 | 12.21 |
| LSD (≤ 5%) | | | | | |
| FYM | 1.38 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |
| | **Melela** | | | | |
| 0 | 10.55 | 10.41 | 12.20 | 11.50 | 11.17 |
| 25 | 12.69 | 13.30 | 12.83 | 13.10 | 12.98 |
| 50 | 13.92 | 13.98 | 14.25 | 14.80 | 14.24 |
| 60 | 15.86 | 14.58 | 15.07 | 14.49 | 15.00 |
| Mean | 13.26 | 13.07 | 13.59 | 13.47 | 13.35 |
| LSD (≤ 5%) | | | | | |
| FYM | 2.63 | | | | |
| Urea | NS | | | | |
| FYM x Urea | NS | | | | |

*equiv = equivalent; FYM = farmyard manure; NS = mean values not significant different
*Moisture (V %) is the mean of samples taken at flowering and maturity stages

### 5.4.5 Economic returns of sorghum production using combined farmyard manure and urea

*The partial budget*

The total variable costs ranged from Tshs 148580 (for the control with no fertilizer applied) to Tshs 1084580/ ha for combined 60 kg N/ha FYM and 60 kg N/ha urea applied (Table 5.22). The cost of harvesting was the most variable across the treatments and ranged from Tshs 126080 for the control (no fertilizer) to Tshs 424960 for 60 kg N/ha FYM and 60 kg N/ha urea. All the treatments produced positive net financial benefits including the no fertilizer inputs option (Table 5.22). The net benefits ranged from Tshs 82,580 (0 kg N/ha urea plus 25 kg N/ha FYM) to Tshs 509020 (60 kg N/ha urea plus 60 kg N/ha FYM).

**Table 5.22:** Partial budget of sorghum production by varying rates of urea and farmyard manure eexperiment

| Treatments | | Adjusted Yield (ton/ha) | Gross field benefits (Tsh/ha) | Cost of fertilizers (Tsh/ha) | Cost of applying Fertilizers (Tsh/ha) | Cost of harvesting (Tsh/ha) | Total variable costs (Tsh/ha) | Net benefits (Tsh/ha) |
|---|---|---|---|---|---|---|---|---|
| Urea (kg N/ha) | FYM (kg N/ha) | | | | | | | |
| 0 | 0 | 1.58 | 472800 | 0 | 0 | 126080 | 148580 | 324220 |
| 25 | 0 | 2.29 | 686400 | 47700 | 57600 | 183040 | 368440 | 317960 |
| 50 | 0 | 3.22 | 964800 | 96561 | 115200 | 257280 | 491541 | 473259 |
| 60 | 0 | 3.37 | 1012200 | 115920 | 115200 | 269920 | 523540 | 488660 |
| 0 | 25 | 2.22 | 667200 | 169000 | 115200 | 177920 | 484620 | 182580 |
| 25 | 25 | 2.62 | 784800 | 216700 | 115200 | 209280 | 563680 | 221120 |
| 50 | 25 | 4.02 | 1207200 | 265561 | 115200 | 321920 | 725181 | 482019 |
| 60 | 25 | 4.08 | 1224000 | 284920 | 115200 | 326400 | 749020 | 474980 |
| 0 | 50 | 3.25 | 974400 | 338000 | 57600 | 259840 | 677940 | 296460 |
| 25 | 50 | 3.79 | 1137600 | 385700 | 115200 | 303360 | 826760 | 310840 |
| 50 | 50 | 4.59 | 1377000 | 434561 | 115200 | 367200 | 939461 | 437539 |
| 60 | 50 | 4.60 | 1380000 | 453920 | 115200 | 368000 | 959620 | 420380 |
| 0 | 60 | 3.60 | 1080000 | 406000 | 57600 | 288000 | 774100 | 305900 |
| 25 | 60 | 4.05 | 1214400 | 453700 | 115200 | 323840 | 915240 | 299160 |
| 50 | 60 | 4.28 | 1284000 | 502561 | 115200 | 342400 | 982661 | 301339 |
| 60 | 60 | 5.31 | 1593600 | 521920 | 115200 | 424960 | 1084580 | 509020 |

* FYM = farmyard manure

*Dominance analysis*

From the analysis, seven treatments gave lower net benefits than the control (0 kg N/ha urea plus 0 kg N/ha FYM) hence were dominated. These treatments were eliminated from further considerations in marginal analysis (Table 5.23).

**Table 5.23:** Dominance analysis of sorghum production by fertilizer application

| Treatments | | | Total costs that vary | Net benefits |
|---|---|---|---|---|
| No. | Urea (kg N/ha) | FYM. (kg N/ha) | (Tsh/ha) | (Tsh/ha) |
| 1 | 0 | 0 | 148580 | 324220 |
| 2 | 25 | 0 | 310840 | 375560 |
| 5 | 0 | 25 | 484620 | 182580 *D |
| 3 | 50 | 0 | 491541 | 473259 |
| 4 | 60 | 0 | 523540 | 488660 |
| 6 | 25 | 25 | 563680 | 221120 *D |
| 9 | 0 | 50 | 677940 | 296460 *D |
| 7 | 50 | 25 | 725181 | 482019 |
| 8 | 60 | 25 | 749020 | 474980 |
| 13 | 0 | 60 | 774100 | 305900 *D |
| 10 | 25 | 50 | 826760 | 310840 *D |
| 14 | 25 | 60 | 915240 | 299160 *D |
| 11 | 50 | 50 | 939461 | 437539 |
| 12 | 60 | 50 | 959620 | 420380 |
| 15 | 50 | 60 | 982661 | 301339 *D |
| 16 | 60 | 60 | 1084580 | 509020 |

D Dominated treatment; * FYM = farmyard manure

*Marginal analysis*

The marginal rate of return for use of urea at 60 kg N/ha plus 60 kg N/ha equivalent farmyard manure was 70% (Table 5.24). Thus for every shilling invested in urea and farmyard manure (60 kg N/ha FYM x 60 N/ha urea), a farmer could recover the Tsh1.00 and gained an additional Tsh 0.70. Similarly, a farmer could expect to get an additional Tsh 0.31, 0.54 and 0.48 if he/she adopted urea alone at 25, 50 and 60 kg N/ha respectively. Marginal net benefits for combinations of 50 and 60 kg N/ha urea with 25 and 50 kg N/ha FYM were negative.

**Table 5.24:** Marginal analysis of sorghum production by varying rates of urea and farmyard manure experiment

| Treatments | | Variable costs (Tsh/ha) | Marginal costs (Tsh/ha) | Net benefits (Tsh/ha) | Marginal net benefits (Tsh/ha) | Marginal rate of return (%) |
|---|---|---|---|---|---|---|
| Urea (kg N/ha) | FYM (kg N/ha) | | | | | |
| 0 | 0 | 148580 | | 324220 | | |
| 25 | 0 | 310840 | 162260 | 375560 | 51340 | 31% |
| 50 | 0 | 491541 | 180701 | 473259 | 97699 | 54% |
| 60 | 0 | 523540 | 31999 | 488660 | 15401 | 48% |
| 50 | 25 | 725181 | 184841 | 482019 | *D | |
| 60 | 25 | 749020 | 23839 | 474980 | *D | |
| 50 | 50 | 939461 | 190441 | 437539 | *D | |
| 60 | 50 | 959620 | 20159 | 420380 | *D | |
| 60 | 60 | 1084580 | 124960 | 509020 | 88640 | 70% |

*Dominated treatment, FYM= farmyard manure

## 5.5 DISCUSSION

### 5.5.1 Effect of combined farmyard manure and urea on *Striga* reproduction and performance

Combined application of 50 and 60 kg N/ha farmyard manure with all rates of urea significantly affected seed production by reducing the maximum *Striga* plants and fecundity. This decrease in seed production coincided with a decrease in *Striga* biomass and numbers. Other researchers have shown that when N fertilizer and organic matter were combined, *Striga* emergence declined over a three year period in farmers' fields (Ransom and Odhiambo, 1994). Ransom (1996) observed that incorporation of crop residues combined with sufficient N fertilizer decreased the adopted urea alone at 25, 50 and 60 kg N/ha respectively. Marginal net benefits for combinations of 50 and 60 kg N/ha urea with 25 and 50 kg N/ha FYM were negative.

**Table 5.24:** Marginal analysis of sorghum production by varying rates of urea and farmyard manure experiment

| Treatments | | Variable costs (Tsh/ha) | Marginal costs (Tsh/ha) | Net benefits (Tsh/ha) | Marginal net benefits (Tsh/ha) | Marginal rate of return (%) |
|---|---|---|---|---|---|---|
| Urea (kg N/ha) | FYM (kg N/ha) | | | | | |
| 0 | 0 | 148580 | | 324220 | | |
| 25 | 0 | 310840 | 162260 | 375560 | 51340 | 31% |
| 50 | 0 | 491541 | 180701 | 473259 | 97699 | 54% |
| 60 | 0 | 523540 | 31999 | 488660 | 15401 | 48% |
| 50 | 25 | 725181 | 184841 | 482019 | *D | |
| 60 | 25 | 749020 | 23839 | 474980 | *D | |
| 50 | 50 | 939461 | 190441 | 437539 | *D | |
| 60 | 50 | 959620 | 20159 | 420380 | *D | |
| 60 | 60 | 1084580 | 124960 | 509020 | 88640 | 70% |

*Dominated treatment, FYM= farmyard manure

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*Striga* seed bank in the soil. From these observations it can be concluded that with a high dosage (50 kg N/ha and above) of combined organic and inorganic fertilizers *Striga* reproduction can be reduced. Seed production depends on *Striga* recruitment or survival to maturity. Integrated N dose affected the interaction between sorghum and *Striga* leading to reduced *Striga* recruitment and hence, reproduction potential. This conclusion is supported by a previous study in which N dose reduced the maximum numbers, biomass and reproductive potential of *Striga* plants (Van Mourik *et al.*, 2008).

Addition of a low quantity of farmyard manure (25 kg N/ha equivalent of farmyard manure) alone increased the number of *Striga* plants and capsules/plant. This could be due to low level of nitrogen supplied by this rate of farmyard manure used because the number of *Striga* plants declined when 25 kg N/ha FYM was combined with urea at 25 kg N/ha and above. Simier *et al.* (2006) reported that *Striga* numbers increased with increasing host tissue N concentration up to 500 mg N per gram host tissue. However, beyond this level, addition of more nitrogen led to decreased *Striga* growth and premature death of *Striga* shoots. The observation in the present study suggests that there is a threshold level of nitrogen fertilization below which increased nitrogen leads to increased *Striga* emergence and above which increased nitrogen fertilization reduces *Striga* emergence. Ayongwa (2006) observed that even at or above the critical root N concentration there still was some *Striga* seed germination. The author suggests that, under field conditions, irrespective of the level of fertilizer application, it is impossible to completely eliminate *Striga* seed germination due to erratic nature of its seedbank in the soil.

Elisaba *et al.* (2000) observed the greatest decrease in mean *Striga* density with the combination of 120 kg N /ha and 20 t/ha manure for maize. Therefore, reduction in *Striga* infestation and long term effect on seed bank can be achieved with high nitrogen rates. Sherif and Parker (1988) found no influence of organic matter on *Striga* in the absence of associated N fertilizer. Van Ast *et al.* (2005) found that reduced emergence of *Striga* strongly reduced the number of flowers hence a reduction in potential seed production. The current study indicates that a high combined dosage of N has lower maximum *Striga* plants, capsules/plants and subsequent seed production.

The mean number of *Striga*/$m^2$, *Striga* biomass and capsules/plant were lower when urea was applied alone than when FYM was applied alone. This may be attributed to the high level of nitrogen released by urea compared to farmyard manure because *Striga* numbers declined with increased level of urea. Since the *Striga* number, biomass and capsules/plant were positively correlated (Kudra, chapter 4), a decrease in *Striga* number is likely to cause a proportional reduction in *Striga* biomass and capsules/plant. Kamara *et al.* (2007) found that N fertilization did not reduce *Striga* infestation in maize under artificial infestation with high doses of *Striga*. The conflicting results imply that N fertilization alone may not be sufficient to control *Striga*.

### 5.5.2 Effect of combined farmyard manure and urea on sorghum performance

The high yields observed from combined farmyard manure and urea applications compared to their sole application is an indication that integrated use of organic and inorganic nutrient sources of N is advantageous over the use of either one alone. This observation is consistent with the findings of other researchers who reported higher crop yields in plots that had organic fertilizers plus inorganic fertilizers than in plots supplied with inorganic fertilizers alone (Mungwe *et al.*, Elisaba *et al.* (2000) observed the greatest decrease in mean *Striga* density with the combination of 120 kg N /ha and 20 t/ha manure for maize. Therefore, reduction in *Striga* infestation and long term effect on seed bank can be achieved with high nitrogen rates. Sherif and Parker (1988) found no influence of organic matter on *Striga* in the absence of associated N fertilizer. Van Ast *et al.* (2005) found that reduced emergence of *Striga* strongly reduced the number of flowers hence a reduction in potential seed production. The current study indicates that a high combined dosage of N has lower maximum *Striga* plants, capsules/plants and subsequent seed production.

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### 5.5.3 The interaction effect of *Striga* numbers and combined farmyard manure and urea on sorghum yield

The reaction of sorghum to the combination of fertilizers and maximum number of *Striga* plants per square meter indicated that at the same N rate the yield was lower when there were more *Striga* plants emerging. The regression of maximum *Striga* numbers on N rate furthermore indicated that the yield effect of fertilizers was greater when infestation levels were lower because at higher N rates the maximum *Striga* counts were lower. This study is in agreement with the findings of an earlier study by Frank *et al.* (2006) and Sauerborn *et al.* (2003) who reported that *Striga* infestation was negatively related to total nitrogen content of the soil. Higher rates of nitrogen fertilizer (from 80 kgN/ha and higher) reduced *Striga* incidence, damage and greatly increased crop yield (Kureh *et al.*, 2003).

### 5.5.4 Implications of using combined farmyard manure and urea for management of *Striga* in sorghum fields

From the perspective of sorghum yield increases and reduced *Striga* reproduction in *Striga*-infected fields, high dosages of up to 120 kg N/ha are required. Combined application of urea and farmyard manure at 60 kg N/ha each reduced *Striga* reproduction by 45% and incidence by

48% across the sites. Similarly, Lagoke *et al.* (1991) reported that application of high dosage of up to 120 kg N/ha fertilizers resulted in 93% reduction in *Striga* incidence. The use of organic manure amendments alone may not be very practicable under the conditions that resource-poor farmers face because of the high quantities of organic manure that are required (Sauerborn *et al.*, 2000). This study showed that urea resulted in sorghum yield increases and was more effective in reducing *Striga* numbers and reproduction than farmyard manure alone. However, accessibility of nitrogen-containing mineral fertilizers is limited (Debrah, 1994). The present study has shown that application small quantities of combined organic and inorganic fertilizers can improve sorghum productivity and reduce *Striga* infestation and reproduction potential.

**5.5.5 Effect of combined farmyard manure and urea on soil physical-chemical properties**

The high moisture retention of plots treated with farmyard manure may be attributed to improved organic matter content. The organic matter could have stabilized soil structure and improved water retention. The favourable soil physical conditions adduced by organic manure are consistent with earlier findings by Agbede *et al.* (2008).

The increase in soil nutrients such as N, P, K, Mg and Cu by farmyard manure application is due to the fact that farmyard manure decomposed and the nutrients were released to the soil. Organic materials have been shown to reduce the P-sorption capacity of the soil and increase P availability (Singh and Jones, 1976; Tooret and Bahl, 1999). The findings on improved P and other nutrients availability corroborates other studies by Avav *et al.* (2009). The low improvement of soil fertility by application of fertilizers at Melela compared to Hombolo could be due to low soil moisture at the farm. There was lower rainfall at Melela (345.5 mm) than at Hombolo (771 mm) during the growing season (Fig. 5.1).

### 5.5.6 Economic returns of sorghum production using combined farmyard manure and urea

The use of combined farmyard manure with urea offers much more economic returns than using urea or farmyard manure alone. Combinations of urea and farmyard manure generally yielded better though responses were very variable across the sites because of the variability of the manure quality and site characteristics. In this study, a high marginal rate of return (70%) was obtained when urea was combined with farmyard manure at rates of 60 kg N/ha each. Nevertheless, most of the farmyard manure rates applied alone and combined farmyard manure and urea rates did not have higher economic returns than when urea was applied alone. This could be due to the low soil fertility status of the fields, *Striga* infestation, high cost of farmyard manure and low quality of farmyard manure used. However, adding farmyard manure in a single year in *Striga* infested field does not immediately change the soil nutrient content and suppress *Striga* infestation (Kranz *et al.*, 1998; Van Mourik, 2007). It is possible that in the long-term, continuous addition of farmyard manure can have suppressing effects on the *Striga,* improve fertility status of the fields and increase economic benefits.

## 5.6 CONCLUSION

The reduction in *Striga* reproduction can be achieved with combinations of urea at 50 kg N/ha and above with different rates of farmyard manure. But integrated *Striga* control method must be envisaged to prevent seed input because there is no single control method which is effective in the control of this weed. Sorghum responded well to combined fertilizers even in the presence of

*Striga* infestation. Therefore, inorganic and organic fertilizers are required for the long-term maintenance of sorghum production, improvement in the N status of the soil and suppression of *Striga* reproduction. In this study, it was observed that most of the combined fertilizer rates had lower economic returns than when urea was applied alone due to the low fertility status of the study fields and high *Striga* infestation. This calls for long-term studies on the impact of these rates on sorghum productivity and *Striga* infestation.

# CHAPTER 6

# GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 6.1 GENERAL DISCUSSION

The field survey showed that *Striga* may have increased over time. For farmers, *Striga*, rainfall and birds were the priority crop production constraints. Hence, the *Striga* problem is not the only one of the constraints farmers face. Farmers cited constraints including rainfall and soil fertility, which a majority of *Striga* scientists have often linked to worsening *Striga* infestations. In fertile soils with high nitrogen and organic matter levels, *Striga* is not a major problem and yields are much higher. Farmers need to use fertilizers in order to raise soil fertility. This constraint poses a real problem to crop production and *Striga* infestation. It is suggested that for comprehensive *Striga* control, the *Striga* problem should not be looked at in isolation but should encompass consideration of the constraints that the famers mentioned like birds, drought and diseases.

Within the study period, fertilizers reduced *Striga* reproduction, but the number of seeds produced was often still high enough to increase the soil seed bank (chapters 4 and 5). Sauerborn *et al*. (2003) showed that fields that have been fertilized consistently had the lowest *Striga* seed densities. Such observations may give rise to the optimism that improving soil fertility would result in reduced *Striga* seed bank. However, it is suggested that the use of low quantities of fertilizers will likely result in increased *Striga* seed bank.

The results of this study demonstrate that use of fertilizers often leads to sorghum grain yield increases (Chapter 4 and 5). An increase in grain yield was directly related to the amounts of N applied in form of urea and organic manures. However, when the infestation levels are high, *Striga* pressure increases especially when manure is added for the first time. At higher N input the reduction in *Striga* numbers occurred faster (chapter 5). It has been previously reported that continuous organic matter addition, even under high *Striga* pressure, increased grain yield and reduced *Striga* infestation (Kranz *et al.*, 1998).

On soil seedbank replenishment (Chapter 4 and 5), it is observed that use of moderate to high levels of fertilizers can reduce seed inputs to seed bank. If high levels of fertilizers can be combined with other control measures, there is space for optimization of *Striga* control in terms of seed bank replenishment. Results from a modelling study indicated that at least 6 years of sustained effort would be needed to reduce the *Striga* seed bank to less than 2% of its original density, no matter how efficient the control technique (Van Mourik *et al.*, 2008). Therefore, control options should not aim at short-term complete eradication of *Striga* but rather aim at simultaneously suppressing *Striga* seed bank replenishment to an absolute minimum and limiting the negative effect of *Striga* on yields.

The study indicates that chicken manure is a valuable fertilizer whose use needs to be encouraged. An application rate of 2.5 t/ha was capable of increasing yields by 234% over the control while FYM, TSP and urea did not have significant effects on sorghum yield. Further, the results of this study indicate that chicken manure, urea and TSP can greatly reduce *Striga* seed inputs by reducing the number of capsules/plant. It is recommended to farmers to use fertilizers in combination with other *Striga* control options that will prevent seed inputs and build up of seedbank.

Combined application of 50 kg N/ha urea and above with farmyard manure, had negative effects on *Striga* numbers, reproduction and positive effect on yield of sorghum. Therefore, a combination of organic and inorganic fertilizers will definitely form a part of reliable control measures.

The current study has shown that high yield of sorghum was obtained by the application of urea in combination with farmyard manure. The higher yield obtained with combined farmyard manure and urea can be attributed to increased nutrient availability and uptake, resulting in greater filled grains per panicle. Continuous use of FYM with inorganic fertilizers not only increases the availability of nutrients but also improves soil fertility and ultimately enhances crop production. Thus, combined use of inorganic fertilizers and organic sources has been suggested to increase the yields of sorghum beside improving the soil fertility status. Enhanced yield in the long-term will offset in part the cost of fertilizer and more benefit will be realized by farmers.

In view of the constraints that farmers face, long-term soil fertility improvements that do not pay off in the first year(s) may not be worth the investment in cash and labour (chapter 5). Control options that imply investments in the short term without simultaneous benefits are not likely to be acceptable to farmers. The question is getting over the problem of the high cost of fertilizer and also the inadequate organic manure supply. Markets for sorghum farm produce at prices that are profitable to farmers remain a key driver for adoption of sustainable soil management options that would reduce *Striga* infestation and improve sorghum productivity.

## 6.2 CONCLUSION

Most of the farmers did not use any of the *Striga* control strategies. Hence, the recommended research based agronomic practices for the control of *Striga* have not yet found large scale application on farmers' fields in the sorghum cropping systems in Dodoma and Morogoro regions of Tanzania. Among soil nutrients, potassium was found to strongly influence *Striga* reproduction. Nevertheless, agronomic practices currently used by farmers greatly influence *Striga* reproduction and infestation. Therefore, it is essential to create a platform for farmers, extension workers and researchers to plan, experiment and discuss integrated *Striga* management strategies. In this way, farmers' knowledge can be complemented with the researchers' knowledge in the search for an integrated *Striga* management strategy.

Application of chicken manure and combination of urea with farmyard manure can result in yield improvements and also lead to reduction of *Striga asiatica* seed inputs and seed bank. However, use of low levels of farmyard manure enhanced *Striga* reproduction. It should be taken into account that no single *Striga*-control component can give a 100% control of the parasite. Through a combination of control options (ISM) has proven to be effective in reducing *Striga.* Example, the regression analysis showed that intercropping sorghum with legumes species and application of fertilizers improved soil N and reduced *Striga* infestation.

## 6.3 RECOMMENDATIONS

The present study has opened up new areas of research in the use of fertilizers to reduce *Striga* reproduction and improve grain yield of sorghum in semi arid areas of Tanzania. The research areas include:

i. Establishing the effect of integrated mineral N and chicken manure on *Striga* reproduction

ii. Investigating the mechanisms by which N, P and K fertilizers affect *Striga* reproduction

iii. Establishing effect of the long-term application of organic manure on *Striga* reproduction and soil fertility improvement

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# APPENDIX 1

**Questionnaire for farmers**

**About the interviewer and the research**

Personal introduction (interviewer)

Rationale for the information

About the interviewee

Name……………………………………….

Sex…………………………………………

Position in the community……………………..

**Key questions**

1. What are the main constraints to cereal (sorghum) production in this region?

   a)………………

   b)…………………..

   c)………………………

   d)…………………………….

2 How can you rate *Striga* as constraints to cereal (sorghum) production? ..................

3 When was *Striga* seen for the first time on the farm?

1-5 years…………….

5- 10 years………..

>20 years………….

4. What has been the trend in *Striga* infestation for the last five years?

a) …………………………

b) ………………………

C) ……………………………

5. What factors in your opinion have contributed to the observed trend?

a)…………………………

b)…………………………

c)…………………………..

d)……………………………

6. How is *Striga* spread?

a)…………………………..

b)…………………………

c)…………………………….

d)………………………………

7. What are some of the methods used in *Striga* control?

a)……………………

b)……………………

c)……………………..

d)………………………

8. How much yield do you currently get?

a) ……………………..

b) ……………………..

c) ………………………

9. What are the cropping systems for sorghum?

a)…………………..

b)……………………..

10. What agricultural inputs did you use?

a)………………

b)………………

c)…… ……………

**Rationale for the information collected**

Capture constraints to cereals production

Capture *Striga* problem and infestation history

Capture the yields farmers' gets

Check if there are any management activities for *Striga* applied by farmers

Agronomic practices which may cause increased/decreased *Striga* infestation

APPENDIX 2

SOKOINE UNIVERSITY OF AGRICULTURE
FACULTY OF AGRICULTURE
DEPARTMENT OF SOIL SCIENCE

## GENERAL GUIDE FOR THE INTERPRETATION OF SOIL ANALYTICAL RESULTS

| Determination | LOW less than | MEDIUM | | | HIGH More than |
|---|---|---|---|---|---|
| pH | 5.0 | 5.0 | - | 7.0 | 7.0 |
| Cond mmhos 1:5 $H_2O$ | 0.5 | 0.5 | - | 1.5 | 1.5 |
| Sol Na meq/100 g ads | 1.0 | 1.0 | - | 3.0 | 3.0 |
| Sol K meq/100 g ads | 0.2 | 0.2 | - | 0.6 | 0.6 |
| Sol Mg meq/100 g ads | 0.3 | 0.3 | - | 1.0 | 1.0 |
| Exch Na meq/100 g ads | 0.3 | 0.3 | - | 1.0 | 1.0 |
| Exch K meq/100 g ads | 0.2 | 0.2 | - | 0.6 | 0.6 |
| Exch Mg meq/100 g ads | 0.5 | 0.5 | - | 4.0 | 4.0 |
| Exch Ca meq/100g ads | 4.0 | 4.0 | - | 10.0 | 10.0 |
| Exc meq/100g ads | 5.0 | 5.0 | - | 15.0 | 15.0 |
| CEC meq/100 g ads | 6.0 | 6.0 | - | 25.0 | 25.0 |
| % Base saturation | 10 | 20 | - | 60 | 60 |
| % Total N ods | 0.1 | 0.1 | - | 0.3 | 0.3 |
| % Orga C ods | 1.5 | 1.5 | - | 4.5 | 4.5 |
| Avail P (Olsen) ppm ads | 5 | 5 | - | 15 | 15 |
| Avail P (Bray) ppm ads | 15 | 15 | - | 30 | >30 |
| Total P ppm ods | 200 | 200 | - | 1000 | 1000 |
| Total K ppm ods | 4000 | 4000 | - | 10000 | 10 000 |
| Total Mg ppm ods | 2000 | 2000 | - | 10000 | 10.000 |
| Total Na ppm ods | 200 | 200 | - | 600 | 600 |
| Total Cu ppm ods | 20 | 20 | - | 100 | 100 |
| Total Mn ppm ods | 200 | 200 | - | 2000 | 2000 |
| Total Zn ppm ods | 40 | 40 | - | 150 | 150 |
| Total Ni ppm ods | 10 | 10 | - | 100 | 100 |
| Total Cr ppm ods | 10 | 10 | - | 100 | 100 |
| Total S ppm ods | 100 | 100 | - | 800 | 800 |
| % Total $Fe_2O_3$(perchloric) | 1.0 | 1.0 | - | 7.0 | 7.0 |
| % Free $Fe_2O_3$ (Dithionite) | 1.0 | 1.0 | - | 5.0 | 5.0 |
| Exch Al meq/100 g ads | 0.5 | 0.5 | - | 4.0 | 4.0 |

ANNEX III. GUIDE TO GENERAL SOIL FERTILITY EVALUATION

(a) Organic matter and total nitrogen contents

| | very low | low | medium | high | very high |
|---|---|---|---|---|---|
| Organic matter (%) | <1.0 | 1.0-2.0 | 2.1-4.2 | 4.3-6.0 | >6.0 |
| Organic Carbon (%) | <0.60 | 0.60-1.25 | 1.26-2.50 | 2.51-3.50 | >3.5 |
| Total nitrogen (%) | <0.10 | 0.10-0.20 | 0.21-0.50 | >0.50 | |

C/N ratios give more information about the availability of nitrogen to plants than total N levels only. C/N ratios indicate the quality of the organic matter as follows:

C/N 8-13: good quality
C/N 14-20: moderate quality
C/N >20: poor quality.

(b) Soil reaction (pH)

Soil pH in water is classified as follows:

| | |
|---|---|
| extremely acid | pH < 4.5.1 |
| very strongly acid | pH 4.5-5.0 |
| strongly acid | pH 5.1-5.5 |
| medium acid | pH 5.6-6.0 |
| slightly acid | pH 6.1-6.5 |
| neutral | pH 6.6-7.3 |
| mildly alkaline | pH 7.4-7.8 |
| moderately alkaline | pH 7.9-8.4 |
| strongly alkaline | pH 8.5-9.0 |
| very strongly alkaline | pH> 9.0 |

(c) Available phosphorus

Available phosphorus is determined by the Kurtz-Bray I method if the soil pH H20 (water) is less than 7.0; and by the Olsen method if the soil pH H02(water) is more than 7.0.

| | low | medium | high |
|---|---|---|---|
| vail.P(Kurtz-Bray I)mg/kg | <7.0 | 7.0-20.0 | >20.0 |
| 'ail P(Olsen) mg/kg | <5.0 | 5.0-10.0 | >10.0 |

) Cation exchange Capacity (CEC)

| | very low | low | medium | high | very high |
|---|---|---|---|---|---|
| (cmol(+)kg⁻¹) | <6.0 | 6.0-12.0 | 12.1-25.0 | 25.1-40.0 | >40.0 |

(e) Exchangeable bases

Calcium

| | very low | low | medium | high | very high |
|---|---|---|---|---|---|
| In clayey soils rich in 2:1 clays $Ca^{2+}$ (cmol(+)$kg^{-1}$) | <2.0 | 2.0-5.0 | 5.1-10.0 | 10.1-20.0 | >20 |
| In loamy soils $Ca^{2+}$ (cmol(+)$kg^{-1}$) | <0.5 | 0.5-2.0 | 2.1-4.0 | 4.1-6.0 | >6.0 |
| In Kaolinitic and sandy soils $Ca^{2+}$ (cmol(+)$kg^{-1}$ | <0.2 | 0.2-0.5 | 0.6-2.5 | 2.6-5.0 | >5.0 |

Magnesium

| | very low | low | medium | high | very high |
|---|---|---|---|---|---|
| In clayey soils $Mg^{2+}$ (cmol(+)$kg^{-1}$ | <0.3 | 0.3-1.0 | 1.1-3.0 | 3.1-6.0 | 6.0 |
| n sandy soils $g^{2+}$ (cmol(+)$kg^{-1}$ | <0.2 | 0.2-0.5 | 0.6-1.0 | 1.1-2.0 | >2.0 |

te: Approximate optimum range of exchangeable Ca:Mg ratio for most crops is 2:1 to 4:1

**assium**

| cmol(+)$kg^{-1}$) | very low | low | medium | high | very high |
|---|---|---|---|---|---|
| layey soils | <0.20 | 0.20-0.40 | 0.41-1.20 | 1.21-2.00 | >2.00 |
| oamy soils | <0.13 | 0.13-0.25 | 0.26-0.80 | 0.81-1.35 | >1.35 |
| andy soils | <0.05 | 0.05-0.10 | 0.11-0.40 | 0.41-0.70 | >0.70 |

Favourable Mg:K ratios for most crops are in the range of 1 to 4

n

| | very low | low | medium | high | very high |
|---|---|---|---|---|---|
| ol(+)$kg^{-1}$) | <0.10 | 0.10-0.30 | 0.31-0.70 | 0.71-2.00 | >2.00 |

ore important than the absolute level of exchangeable $Na^{+}$ is the xchangeable sodium percentage (ESP) obtained by dividing exchangeable a+ by the CEC multiplied by 100. Soils are considered sodic when the SP >15. Generally the exchangeable $Na^{+}$ of less than 1.0 cmol(+)$kg^{-1}$ is eferred by most crops.