EFFECTIVENESS OF REDUCED RATES OF N ON PRODUCTIVITY AND ECONOMIC RETURNS OF SORGHUM IN *STRIGA* INFESTED SEMI-ARID AREAS OF TANZANIA

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ABSTRACT

Performances of three sorghum (*Sorghum bicolor* L. Moench) genotypes (Wahi, Hakika and Pato) and inorganic soil amendments were studied under naturally *Striga asiatica* [L.] Kuntze infestation for one cropping season (2015/16) in two locations, using a split plot design laid out in a randomized complete block design with four replications. A susceptible sorghum (Pato cultivar) was used as a bioassay to evaluate the effectiveness of reduced rates of N under *Striga* infestation. At Hombolo, 40 Kg N/ha had significantly (P< 0.05) lower emerged *Striga* shoots count/m^2 than all other rates of N, except at 11 WAP. Yields with 30 Kg N/ha (0.64t/ha) was significantly (P< 0.05) lower than yields from all other rates of nitrogen (1.08 - 1.52t/ha). At Ngamu, fertilization played no significantly (P< 0.05) role in *Striga* emergence and attachment. Yields with 10 Kg N/ha (4.89t/ha) was significantly (P< 0.05) lower than yields from all other rates of nitrogen (5.2 – 6.0t/ha). Across locations, variety Hakika had significantly (P< 0.05) fewer emerged *Striga* shoots count/m^2 compared with varieties Wahi and Pato. At Hombolo, Yields on Hakika variety (0.96t/ha) was significantly (P< 0.05) lower than the yield in all other varieties (1.21 - 1.28t/ha). At Ngamu, variety Pato gave more yields (7.21t/ha than other varieties (2.81 – 5.95t/ha). This study showed that the most effective rates of nitrogen; 40 and 60 Kg N/ha (Hombolo) and 50 Kg N/ha (Ngamu) should be promoted in semi-arid areas of Tanzania where *Striga* poses a serious threat. Results also showed that varieties Hakika and Wahi proved their resistance/ tolerance to *Stiga asiatica* compared to variety Pato.

DECLARATION

I, Mashenene Malima, hereby declare to the senate of the Sokoine University of Agriculture that, this dissertation and associated outputs are the product of my original work done within the period of registration and has never been submitted by anyone before nor beingconcurrentlysubmitted for a degree award to any other University.

_____   _____

Mashenene Malima,   Date

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The above Declaration is confirmed

_____   _____

Prof. K.P. SIBUGA   Date

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DEDICATION

To almighty God, my beloved parents Mr. and Mrs. Charles BiswaroMalima who laid the foundation of my carrier. My special dedications are addressed to my lovely fiancé, Sholastika Mahundi and my children Cornel and Bray Mashenene without living behind all ARI-Hombolo staff who missed me a lot when I was undertaking the course of my study and their patience which enabled me to complete my work. I would like also to dedicate this work to Josephine Africa who was very helpful and took care of my lovely child and the family as a whole in my absence.

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LIST OF ACRONYMS AND ABBREVIATIONS

%	Percentage
^{0}C	Celsius degrees
ARI	Agricultural Research Institute
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
BMGF	Bill and Melinda Gates Foundation
BS	Base saturation
Ca^{2+}	Calcium
CEC	Cation Exchange Capacity
CDFA	California Department of Food and Agriculture
C:N	Carbon to Nitrogen ratio
CV	Coefficient of Variation
EABL	East Africa Breweries Limited
ECA	Eastern and Central Africa
ECARSAM	Eastern and Central Africa Regional Sorghum and Millet Network
ESA	Eastern and Southern Africa
FACTFISH	World Statistics and Data Research
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
Fig	Figure
F-STAT	Fixation Statistics/ Index
GenStat	General Statistics

GM	Gross Margin
ha	Hectare
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
ISM	Integrated *Striga* Management
K^+	Potassium ion
Kg	Kilogram
m^2	Squared meter
MAFC	Ministry of Agriculture, Food Security and Cooperatives
m.a.s.l	Meter above sea level
Mg^{2+}	Magnesium ion
N	Nitrogen
Na^+	Sodium ion
Ns	Non significant
OC	Organic Carbon
OM	Organic Matter
P	Probability
P	Phosphorus
pH	Potential hydrogen
SAT	Semi-Arid Tropics
SSA	Sub Saharan Africa
TEB	Total Exchangeable Bases
TMA	Tanzania Meteorological Agency

TR	Total Revenue/Income
Tsh	Tanzania shilling
TSP	Triple Super Phosphate
TVC	Total Variables Cost
USD	United State Dollar
USDA	United States Department of Agriculture
WAP	Week after planting
WFP	World Food Programme
WWW	World wide web
X-stics	Characteristics

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Globally, Sorghum, [*Sorghum bicolor* (L.) Moench] is the fifth most important staple food crop after wheat, rice, maize and barley (FAO, 2012). Across ecologies in Africa, Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA, 2013) reported that sorghum is the second major crop (after maize) and is one of the main staples for people in East and Southern Africa (ESA). In Tanzania, sorghum is one of the primary staple food crops. It ranks fourth among the most important crops grown next to rice, maize, and wheat, both in area coverage, and production (Leliveld *et al*., 2013). In Dodoma and Singida regions sorghum is the principal sources of food and income upon which rural livelihoods are based (Kilasara *et al*., 2015; Mahinda *et al*., 2016). Its demand is now becoming increasingly greater than maize, sunflower and groundnut that were previously considered to be more important than sorghum (Rohrbach and Kiriwaggulu, 2007). It supports millions of people serving as a source of food, feed, fiber, building material and bio-fuel (EABL, 2011; Mahinda *et al*., 2016).

Sorghum is widely found in the drier areas of the region, as it can withstand drought and periods of water logging (Letayo *et al*., 1996; Monyo *et al.,* 2004). Traditionally, a staple food crop and source of income for millions of people in the semi-arid tropics (SAT) of Africa and Asia, and remains an important food security crop in sub-Saharan Africa (SSA) and especially in the marginal areas where other crops do not do well (Mbwika *et al.,* 2011). Over 90% of the sorghum produced in the region

is directly consumed by humans. The Plurality of household food requirements, in both caloric and nutritional measures, is 11.3% protein, 3.3% fat and 56–73% starch, relatively rich in iron, zinc, phosphorus and B-complex vitamins (MacOpiyo *et al.*, 2009). The crop is grown in the tropical and subtropical regions of the world between 40°N and 40°S of the equator. Globally, sorghum is currently grown on an area of 45 million ha. In East and Central Africa (ECA) sorghum is grown on an area of approximately 10 million hectares (Mitaru *et al.*, 2012). In Tanzania, have been reported by AGRA, (2013) that the total area under cultivation of field crops is 13.3 million ha, of the total area covered by field crops 67% (8.91 million ha) is under cereals, out of which sorghum accounts for 13.17%.

Although the value of the crop has increased substantially, its supply to meet industrial market demand is still low (ECARSAM, 2014; EABL, 2013). This is partly because sorghum is still produced in a traditional way that depends on the natural rainfall, which is erratic and unpredictable (Chang'a *et al.*, 2010). The yields obtained are usually below farm's potential, with stagnant or decreasing trends with time (World Food Programme, 2012). Farmers keep on expanding their farms believing that the yield per unit area would increase (Ahmed *et al.*, 2011).

In Tanzania, sorghum is grown in the central zone, covering Dodoma and Singida regions, Lake Zone covering Mwanza, Mara and Shinyanga regions, and southern zone covering Lindi and Mtwara regions (MAFC, 2010; ECARSAM, 2014 and Kilasara *et al.*, 2015). Area planted with sorghum fluctuates from one year to another. Area planted with sorghum decreased from 874,220 hectares in 2008/09 to

618,369 hectares in 2009/10. This is equivalent to 29.27% decrease (MAFC, 2010). According to FAOSTAT (2013) the average yield of sorghum is 1.17 tones/hectare in Tanzania, which is less than the world average yield (1.48 tones/hectare). According to Taye *et al*., (2013) the genus *Striga* (*Orobanchacea*) is a major constraint in sorghum productivity, losses due to *Striga* actually surpass the national sorghum grain requirements as yield losses averaged 24% (10 – 31%) but in areas of heavy infestation, losses reached 90 –100% in some years (Ikie *et al*., 2007).This situation may lead to the problem of hunger and malnutrition, which is a significant obstacle to economic growth (FAO, 2010). In Dodoma, Singida and Tabora regions of Tanzania, 45-55% of the households are food insecure (WFP, 2007). This situation may be due to higher spread of *Striga* weed in the ecological zones.

1.2 Justification

The genus *Striga* has become not only a biological constraint to food production in Sub-Saharan Africa but also a socio - economic problem for resource poor farmers (Ikie *et al.,* 2007). FAO and ICRISAT, (1996) estimated a loss > 7 billion USD, adversely affecting 300 million people worldwide. But in SSA the yield loss is estimated at 8.8 million with a value of 2.5 billion USD.

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).Most effective control technologies involved high input agriculture such as the use of ethylene in the USA which achieved 92% depletion of viable *S. asiatica* seed with a single application of ethylene at 1.6kg/ha (Bebawi *et al.,* 1985). However such high input control systems may not be an appropriate control technology for the majority

of the resource poor farmers suffering from *Striga* infestation in Sub-Saharan Africa (Ikie *et al*., 2007). Hence there is a need to look for simpler techniques as components of an integrated *Striga* control package, which is adaptable to the African situation (Ikie *et al.,* 2007). Therefore, the current study was conducted to evaluate the efficient and affordable method of controlling *Striga* weed by small holder farmers using different rates of nitrogen fertilizer in some sorghum genotypes.

1.3 Objectives

1.3.1 Overall objective

The overall objective of this study was to develop an Integrated *Striga* Management (ISM) package based on sorghum genotypes and plant nutrient sources for semi-arid areas of Tanzania.

1.3.2 Specific objectives

1. To evaluate the performance and yield response of sorghum to *Striga* infestation under different rates ofnitrogenous fertilizer.

2. To quantify the agronomic efficiency of using reduced rates of N from the recommended rate of fertilizers in reducing the impact of *Striga* growing together with sorghum.

3. To determine the economic benefit of using fertilizers in sorghum production in *Striga* infested fields.

CHAPTER TWO

2.0 LITERATURE RIVIEW

2.1 General Plant Descriptions

Sorghum is an upright, short-day, summer annual that is a member of the Poaceae or grass family. The grass blades are flat, stems are rigid, and there are no creeping rhizomes. Sorghum has a loose, open panicle of short, few-flowered racemes. As seed matures, the panicle may drop. Glumes vary in color from red or reddish brown to yellowish and are at least three quarters as long as the elliptical grain. The grain is predominately red or reddish brown (Barkworth, 2003).

Sorghums exhibit different heights and maturity dates depending on whether they are grain sorghums (*Sorghum bicolor* ssp. *bicolor*), forage sorghums *(Sorghum bicolor)*, Sudan grass *(Sorghum bicolor* ssp. *drummondii*), or sorghum-Sudan grass hybrids *(Sorghum bicolor* x *Sorghum bicolor var. sudanense)*. Growth characteristics also vary depending on the location grown, inputs, and agronomic practices. In general, forage sorghums are taller plants with later maturity dates and more vegetative growth than grain sorghums. Sudangrass and sorghum-Sudangrass hybrids fall in between grain sorghums and forage sorghums in height (Undersander, 2003).

2.2 Sorghum Domestication and Production

The geographic place of origin and initial domestication of sorghum is in Africa. Ethiopia particularly, south-western is believed to be the center of origin and domestication of sorghum [*Sorghum bicolour* (L.) Moench] (Doggett, 1988; Wortmann *et al*., 2006). This is owing to the existence of the largest diversity of

sorghum innortheast Africa. Conversely, Stemler *et al*., (1975) argued that none of the bio-geographical, morphological, historical, or evolutionary evidence supported the claim that sorghum was domesticated or originated in Ethiopia. However, in many crop species the wild ancestors are found at the center of origins and they represent an important source of variation and adaptive traits for breeding. Extricationally, the origin and distribution of sorghum diversity is potentially important to its future utilization and conservation.

Sorghum occurs both as weedy species in Africa's savannah ecosystems (Wood and Lenne, 2001) and as a cultivated cereal. Cultivated sorghum species is classified as *Sorghum bicolour*L. Moench and comprises five major races (*Guinea (G), Durra (D), Caudatum (C), Kafir (K), and Bicolor (B)*) based on spikelet and panicle characteristics (Harlan and Dewet, 1972). Conversely, Obilana *et al*., (1996) reported that four major basic races of the cultivated sorghum are grown in Tanzania, with the exception of the *Kafir* race.

Following domestication, genetic admixture or introgression or hybridization events probably occurred between wild and cultivated species. Subsequently, thousands of years of selection in response to diverse physical environments and human needs, genetic drift, and natural inter-crossing among the different sorghum races have contributed to sorghum diversity. The contributions of sorghum assortment have allowed sorghum to be grown in a variety of environments (Doggett, 1988). At present, sorghum is an important cereal crop with remarkable genetic diversity with more than 22,000 accessions kept in the world sorghum collection in India (Kimber, 2000).

Globally sorghum production trends shows that, yield increased from 40 million tons during early 1960s to 66 million tons in early 1980s. By early 1990s, it had fallen to about 58 million tons due to rainfall variability. However, it rose to 64 million tons by 1996, and was 73 million tons in 2005, before it went down to 55.6 million tons in 2010 as a result of low rainfall. The global increment of area under sorghum cultivation has shown a general slight decline of about 0.2%/yr, and yield of 0.5%/yr, before 2000 (USDA, 2003; FAO, 2004). FAOSTAT (2011) reported the United States of America as the top sorghum producer with a harvest of 9.7 million tones followed by India, Nigeria, Sudan, and Ethiopia.

Globally, Tanzania was ranked number 16 in sorghum production (FACTFISH, 2014). In 1960, the production level was 180,000 tons, and then went down to 171,900 tons in 1970 (Mahinda *et al*., 2014). In 1980 the level of production increased to 510,000 tons and dropped down by 9.02% in 1990 and then rose by 22.43% to 598,200 in 2000 (FAOSTAT, 2014).

2.3 Constraints to Sorghum Production.

The livelihoods of millions of households in East and Central Africa depend on sorghum production (Rebeka *et al.,* 2013; MacOpiyo *et al*., 2009). Conversely, In East and Central Africa (ECA) the crop is grown on an area of approximately 10 million ha (Mitaru *et al*., 2012). However, its productivity in Tanzania is low at about 1.17 ton ha^{-1} (FAOSTAT, 2013). This is attributed to a number of abiotic and biotic stresses. Yield reducing constraints include low soil fertility (nutrient deficiency), drought, lack of irrigation facilities, inadequate infrastructure, information barriers, less productivity enhancing technologies (<20% use improved

seeds), weeds, birds, disease, insect pests and pathogens (Kanyeka *et al.,* 2007; Taye *et al.,* 2013). Although these constraints cause a significant loss of grain, the level of losses varies from region to region. In Tanzania, *Striga* is a major production constraint in most sorghum producing areas. The weed limits the productivity of the crop by allelopathy, competition for nutrients and limiting the expression of the full genetic potential of sorghum plants.

In semi-arid zone of Tanzania, drought and *Striga* are reported to be the most important sorghum production constraints in the marginal lands (Kilasara *et al.*, 2015). Consequently, the current research was conducted in the central zone of Tanzania, which represents Tanzania's sorghum growing belts. Although both drought and *Striga* are equally important problems in sorghum, this research focused on integrated *Striga* management to enhance sorghum productivity.

2.4 *Strig*a a Parasitic Weed of Sorghum

2.4.1 Quantification of the *Striga* problem

The genus *Striga* belongs to the family *Orobanchaceae* (formerly: *Scrophulariaceae*). The Genus is a major biotic pest in the savannah region (Ayongwa *et al*. 2011).This genus parasitizes on cereal crops such as rice (*Oryza glaberrima* Steudel and *O. sativa* L.), pearl millet (*Pennisetum glaucum*L. R. Br.), maize (*Zea mays* L.), and sorghum (*Sorghum bicolor* [L.] Moench) (Parker, 1991; Johnson *et al*., 1997). It also parasitizes many wild grass species in Africa. There are more than 50 species of *Striga*, with several species affecting the production of cereals and legumes in sub-Saharan Africa and Asia (Parker and Riches, 1993; Kiruki *et al*., 2006).

The *Striga* species are among the most specialized of all root-parasitic plant parasites (Parker and Riches, 1993). *Striga* combines the life styles of both a holo-parasite at the seedling stage and a hemiparasite as a green, chlorophyll-containing emergent plant (Mohamed *et al*., 2001). Of the parasitic species of *Striga*, *S. hermonthica, S. asiatica, S. aspera, S. forbesii* and *S. gesnerioides* are of particular economic importance as crop parasites in Africa (Mohamed *et al*., 2001; Mac Opiyo *et al*., 2009). These species attack all the important tropical cereals except *S. gesnerioides* which parasitizes only legumes.

Striga asiatica is perhaps the most destructive as compared to the other *Striga* species in cereal production in the savannah region (Kudra *et al*., 2012).The species is the most widespread of the *Striga* species (Cochrane and Press 1997). It has a very wide geographic distribution, native to sub-Saharan Africa, and many countries in tropical Asia (southern and eastern). It attacks sorghum, maize, millet, sugar cane and upland rice (Mbwika *et al.,* 2011).

2.4.2 Biological Description of *Striga*

Striga asiatica seedlings are not visible above ground, but white succulent shoots can be found attached to living host roots. Mature plants are characterized by bright-green stems and green foliage above ground and that is sparsely covered with coarse, short, white, bulbous-based hairs. *S. asiatica* are normally 15-30cm tall but have grown to 60cm. Leaves are nearly opposite, narrowly lanceolate, about 1-3cm long, with successive leaf pairs perpendicular to one another. *S. asiatica* flowers in summer and fall. Flowers are small (less than 1.5cm in diameter) are sessile, axillary, the corolla is two-lipped, and they occur on loose spikes. Flower color varies

regionally, from red, orange, or yellow in Africa to pink, white, yellow, or purple in Asia. The flowers give way to swollen seeds pods, each containing thousands of microscopic seeds. Underground stems are round with scale-like leaves and white but turn blue when exposed to air. The roots are succulent, round, without root hairs, and found attached to a living host species root system for germination and initial development (CDFA, 2006; *www.invasive.org*, 2006).

2.4.3 Geographical Adaptation of *Striga*

Striga is highly adapted to its environment, occurs in tropical areas with an annual rainfall ranging from 300 to 1200 mm (Kudra *et al*., 2014). 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). It will only germinate in response to specific chemical cues (i.e. plant exudates) received from the host plant. Once germinated, however, *Striga* integrates itself with the host plant, attaching itself to the vascular system within the host plant for water and nutrients, wounds the outer root tissue and weakens the host plant`s ability to maintain its normal growth patterns by impairing photosynthesis (MacOpiyo *et al*., 2009). *Striga* exerts a potent phytotoxic effect on its host causing severe stunting and a characteristic "be witched" and chlorotic whorl. As a result, plant performance is severely degraded by *Striga* with a large reduction in host plant height, biomass, and ultimately grain yield (MacOpiyo *et al*., 2009).

Striga can spread quickly to other fields and neighbouring farms. *Striga* seeds are tiny, and a single plant cans produceup to500, 000 seed (Bebawi *et al*., 1984; Berner

et al., 1994). The seeds can remain viable in the soil for as long as 20 years (Ikie *et al*., 2006). Often times the seeds are transmitted accidentally by farmers travelling across fields (Kudra *et al.,* 2012).

2.4.4 Distribution of *Striga* in Tanzania

The broad distributions of *Striga* across Tanzania have been recorded by different authors (Mbwaga and Obilana, 1993; Riches, 2003). The dominant *Striga* species in the country are *Striga hermonthica (Del.) Benth*, *Striga asiatica (L.) Kuntze* and *Striga forbesii.* Of the three, *S. hermonthica* is the most dominant species and is the predominant specie in the North West of Lake Victoria zone (Mara, Kagera, Tabora and Shinyanga). Widespread occurrence of *Striga asiatica* found at the eastern part of Tanzania (Tanga, Morogoro, Coast, Lindi, Mtwara, Ruvuma, Singida and Dodoma. *Striga forbesii* is the dominant species in areas where Sorghum, rice, maize and sugar cane are mostly grown (MacOpiyo *et al*., 2009). Appendix 1 shows the dominant species of *Striga* in Tanzania.

2.4.5 Extent and Severity of *Striga* Infestation in Tanzania

Tanzania was ranked as one of the most highly infested countries by 2009 in East Africa in terms of hectarage infestations reported almost throughout the country (MacOpiyo *et al*., 2009). The area under *Striga* is estimated to be 963,532 ha, with the highest severity of infestations found along the Lake Victoria in the Mwanza and Mara regions. Much of the rest of Tanzania's *Striga* infestations level are still in the medium to high severity levels and are predominantly in the central semi-arid region and the southern plateau of the country (MacOpiyo *et al*., 2009).

In Tanzania, the areas most severely infested by *Striga* are generally located near Lake Victoria. In these areas, *Striga* density is at least 14 plants per m^2, but often reaches much higher levels (MacOpiyo *et al*., 2009). Further away from Lake Victoria, *Striga* infestation tapers off somewhat, but significant areas of medium (4-9 plants per m^2) and high (9-14 plants per m^2) *Striga* infestation levels occur. *Striga* infestation tapers as you move eastwards of the lake basin and rise with altitude with a cut-off location in the range of about 1,600 meters above sea level. Most of Tanzania has large areas under medium to high levels of *Striga* infestation density, notably throughout its central and southern regions. Only the small pocket of Tanzania near the lake zone is under severe *Striga* infestation, around the Mwanza and Mara regions. The sorghum growing areas of Tabora, Singida and Dodoma are highly infested (MacOpiyo *et al*., 2009).The extent and intensity of *Striga* infestation is illustrated Appendix 2.

2.5 Host-Parasite Association

The domestication and spread of sorghum and *Striga* species are reported to have occurred together (Rao and Musselman, 1987). Consequently, *Striga* most probably evolved in association with sorghum. It is believed that *S. asiatica* originated in the sub-Saharan Africa, where sorghum originated and spread into the rest of Africa and Arabia (Cochrane and Press 1997).

Striga is an obligate hemi-parasite needing a host plant to fulfill its life-cycle. However, due to its chlorophyllous leaves, it undergoes photosynthesis and as such it does not entirely depend on its host for its metabolite requirements (Kuijt, 1969).

Understanding the life cycle of *Striga spp* and their interactions with their hosts allow plant agronomist to develop, employ and scale up several different mechanisms of managingthe host against this parasite.

The life cycle of the parasite follows a series of developmental stages, from seed to seed producing plants.Like many other plant species, *Striga* seeds have a period of primary dormancy before they are able to germinate. A second prerequisite for germination is the preconditioning of the seed, which requires about two weeks of humid and warm (25-35℃) conditions in a moist environment (Vallance, 1950; Parker and Riches, 1993). Conversely, *Striga* will not develop in temperatures below 20 ℃ though the seeds may survive in frozen soil of temperatures as low as −7 C (Kelly *et al.*, 2014).

Preconditioned *Striga* seeds will then need secondary metabolites (xenognosins), which are found in root exudates of their hosts, for germination (Vallance, 1950; Yoder, 2001). Host root exudates contain strigolactones, signaling molecules that promote *Striga* seed germination.

Secondary metabolites serve to direct the radicle of the *Striga* seedling towards the host root (Williams, 1961b). Within four days of germination, the *Striga* radicle needs to find a host root, form a bell-like swell (haustorium), and penetrate the host root (Riopel and Timko, 1995). The haustorium is a specialized organ that connects the parasite to the xylem of the host root, enabling the transport of water and nutrients from the host. As a result, it affects the host plant growth and reduces the

photosynthetic rate in the host (Ejeta and Butler, 2000). The pathogen colonizes underground, where it may spend the next four to seven weeks before emergence, when it rapidly flowers and produces seeds.

During *Striga* infestation the symptoms on the host plant resemble that of other disasters such as drought and diseases (Kilasara *et al*., 2015). These symptoms include stunting, wilting, chlorosis of the host plant and the failure of panicle formation as a result of severe infestations. *S. asiatica* can cause the host plant to appear wilted with leaf rolling even though there may be adequate soil moisture. The problem is most severe under low moisture stress, degraded and infertile soils and this may result to nectroc lesions (Ejeta and Butler, 2000a). Appendix 3 shows the general life cycle of *Striga asiatica* as noted by IITA (1997).

2.6 *Striga* Control Methods

Several measures have been tried and adopted for control of *Striga*. Many potential approaches developed to control this weed include using resistant/tolerant varieties, sowing clean seeds that are not contaminated with *Striga* seeds, rotating cereal hosts with trap crops that include abortive germination of *Striga* seeds, intercropping, applying organic and inorganic amendments such as fertilizer or manure, fumigating soil with ethylene, hoeing and hand pulling of emerged *Striga*, applying post emergence herbicides, push-pull technology and using biological control agents (Babiker, 1996; Atera *et al*., 2011). Despite the mentioned approaches but*Striga*still remains a weed of economic importance in Africa because the majority of its life cycle takes place below ground (Franke *et al*., 2006). Thus, it is not easy to detect

before emergence also is late to reduce crop loss (Rich *et al*., 2004). These approaches developed to control *Striga* weed can be grouped into five independent control options, namely chemical, biological, cultural, host plant resistance and integrated *Striga* control.

2.6.1 Chemical Control

Herbicides tested for the selective control of *Striga* mostly acts through the foliage, although some have soil residual effects. Among the herbicides tested, 2, 4-D has been the most selective and is the cheapest. MCPA (2-methyl-4-chlorophenoxyacetic acid), a compound closely related to 2, 4-D, has also been effective especially when mixed with bromoxynil (Ejeta *et al.,* 1996). Many herbicides are useful in preventing the build-up of *Striga* seeds in the soil but may not prevent damage prior to their emergence (Gworgwor *et al.,* 2002; Kanampiu *et al.,* 2003). Research efforts should therefore be emphasized towards identifying herbicides that persist in the soil, allowing the germination of *Striga* seeds but killing the seedlings before attachment to the host. However, these herbicide options are mostly unaffordable for resource poor farmers.

Development of transgenic herbicide resistant sorghum is reported as an alternative way for the use of herbicide application to immediate *Striga* management through treatment of crop seeds with herbicide as a low cost solution (Haussmann *et al*., 2000a; Joel, 2000; Kanampiu *et al.,* 2003). For instance, herbicide seed treatment using imazapyr or 2, 4-D appears to be a promising approach for the control of *Striga* in maize or sorghum (Kanampiu *et al.,* 2001; Dembele *et al.,* 2005). Ndung‟u

(2009) reported that coating sorghum seed with herbicide reduced *Striga* infestation, *Striga* flowering and *Striga* seed set, and it is considered as the most effective approach as it does not affect sorghum biomass.

2.6.2 Biological Control

Most organisms have natural enemies that balance their populations, avoiding excessive abundance (Templeton, 1982). The basis of biological control is the exploitation of natural enemies of pest species. A prerequisite for the assessment of the prospects for biological control include knowledge of natural enemies and their effect on the population dynamics of the host (Templeton, 1982).

Biological control is particularly attractive in suppressing root parasitic weeds in annual crops because of the intimate physiological relationship with their host plants makes it difficult to apply conventional weed control measures. Currently, biological control using microbes is becoming a critical component of integrated management of *Striga*, given that the bio-control agents are usually host specific, highly aggressive, easy to mass produce and diverse in terms of the number of isolates (Ciotola *et al.,* 1996). Biological control methods are also relatively economical, may be self-perpetuating and are usually free from negative residual effects. Management of *Striga* through bio-control agents is also much safer and less polluting to the environment than the use of chemical pesticides, especially the phenoxy herbicides which are associated with non-target drift problems (Abbasher *et al.,* 1998). The dynamics of both the biotic and abiotic components of the rhizosphere affect *Striga* parasitism, and the efficacy and persistence of bio-control agents (Fen *et al.*, 2007).

Various fungal species are reported to infect *Striga* species. Specific isolates of *Fusarium* species are among the most prevalent pathogens and may be highly pathogenic to *Striga* species (Abbasher *et al.,* 1998). The use of a myco-herbicide, i.e., *Fusarium oxysporum* coated seeds and host plant resistance reportedly reduced *Striga* emergence by 95% and increased sorghum yield by 50% (Franke *et al.,* 2006). But little research has been conducted to study the use of bio-herbicides to control *Striga* (Rebeka *et al.,* 2013).

2.6.3 Cultural Practices

A number of cultural practices have been recommended for *Striga* control such as crop rotation (Oswald and Ransom, 2001); intercropping (Udom *et al*., 2007); transplanting (Oswald *et al*., 2001); soil and water management (Van Delft *et al*., 2000; Reda and Verkleij, 2007); use of fertilizers (Jamil *et al*., 2011); and hand weeding (Ransom 2000) to reduce the production of further *Striga* seed. These methods should also reduce the density of *Striga* seeds already in the soil seed bank (Reda and Verkleij, 2007). Some of these practices improve soil fertility, which will stimulate the growth of the host but also adversely affects germination, attachment and subsequent development of the juvenile *Striga* plants (Reda and Verkleij, 2007). However, this approach has only limited success for small-scale farmers, largely due to socio-economic and financial constraints that prevent the use of adequate amount of nitrogenous fertilizer.

2.6.4 Host Plant Resistance

Host plant resistance would probably be the most feasible and potential method for parasitic weed control byresource-poor farmers (Rich *et al*., 2004; Teka, 2014).This

is due to that the use of resistant crop cultivars is the most economically feasible and environmentally friendly means of *Striga* control. This has been demonstrated in multi-location field tests conducted in Ethiopia and Tanzania (Mbwaga *et al.*, 2007; Tesso *et al.*, 2007). Berhane (2016), confirmed this and found that in East Africa, the most promising new approach to *Striga* control is the use of resistant cultivars (e.g. of Sorghum). Reports of genetic resistance to *Striga* have been documented in various research groups such as in rice (Gurney *et al.*, 2006), Sorghum (*Sorghum bicolor*) (Mohamed *et al.*, 2003; Haussmann *et al.*, 2004; Rich *et al.*, 2004), Cowpea (Riopel and Timko, 1995) and Maize (Menkir, 2006).

Using biotechnological approaches (including biochemistry, tissue culture, plant genetics and breeding, and molecular biology) significant progress has been made in developing screening methodologies and new laboratory assays, leading to the identification of better sources of parasitic weed host resistance (Ejeta *et al.*, 2000b; Haussman *et al.*, 2000a). However, reliance on host resistance alone is not ideal because so far complete resistance against *Striga* has not been attained through breeding (Gurney *et al.,* 2002), and usually the newly developed varieties may not fulfill farmers preference traits (Adugna, 2007). Therefore, integrating genetic resistance with other control measures is the smartest option possible both for effectiveness of control as well as for increasing durability of resistance genes (Ejeta, 2007).

2.6.5 Integrated *Striga* management (ISM) Approach

No single management option have been found effective across locations and time (Berhane, 2016).The integration of multiple control options is suggested as a better

approach to combat *Striga* problem at the farm level (Aliyu *et al.,* 2004; Temam, 2006; Tesso *et al.,* 2007). Several research findings argued that the integration of multiple control methods provides advantages over the application of each method in isolation as can provide a sustainable control over a wide range of biophysical and socio-economic environments (Franke, 2006; Kamara, 2007; Hearne, 2009). Research findings reported the effectiveness of the combined use of cultural agronomic practices, herbicides, germination stimulants, trap-cropping, fertilization, biological control and host plant resistance to control *Striga* species (Tesso *et al.*, 2007).

Integrated *Striga* management approach relies on the use of resistant sorghum genotypes and plant nutrients sourceto control *Striga* emergence and growth lead to effective results (De Groote *et al.*, 2010). However, the proposed ISM approaches have not been assimilated easily yet at the farm level, probably because of the complexity, economic andlabourthat the multiple methods would require.

2.7 Soil Fertility and *Striga*

Several studies have shown that *Striga* infestation is correlated with low soil fertility and that improved soil fertility would lead to a reduction of the infestation (Lakoge *et al.*, 1991; Ahonsi *et al.*, 2004; Patil, 2007; Avav *et al.,* 2009). However, all these studies did not provide any insight into the influence of fertilizers on *Striga* reproduction and long term effect on the *Striga* seed bank. In a study by Cardoso *et al.,* (2010), it was observed that one of the weed's most contributing factors for development is low soil fertility and crop systems in SSA with no external inputs.

According to a study in Benin, focus should only be on *Striga* management when soil fertility "exceeds a threshold value". Otherwise resources will be used without improvement in yields (Abunyewa and Padi, 2003).

Declining soil fertility as well as water stress accentuates the severity of *Striga* infestation to the hosts (Miriam, 2012; Teka, 2014). *Striga* is particulary a pest of low fertile soil and usually the infestation decreases if mineral nutrients, especially nitrogen and phosphorus, are applied in sufficient quantities (Adagba *et al*., 2002). Lagoke *et al*., (1991) found that when the soil is highly degraded and infertile, application of high fertilizer dosages of up to 120 kg N/ha resulted in 93% reduction in *Striga* incidence. In contrast to high dosage by Lagoke *et al*., (1991), Riches (1998) noted thattiming of application of N fertilizers even in small doses was shown to be more effective on the plant's ability to cope with *Striga*.

In Western Kenya, De Groote *et al*., (2010) reported that higher fertilization input on *Striga* infested fields increased yields, but farmers were not able to cover the cost for the extra amount of fertilizer needed. Also, Parker (1984) reported that nitrogen tends to reduce strigol production from the host plants and therefore inhibit germination of *Striga* seeds which results to delay of *Striga* emergence. Other results (Gacheru and Rao, 2001; Sjogren *et al*., 2010) in Western Kenya have indicated that nitrogen and organic C tend to increase vegetative growth of the host plant, which strengthens it while protecting the plant from *Striga* parasitism and crop yield increases. Miriam, (2012) proved the results of Gacheru and Rao (2011); Sjogren *et al*., (2010) in Western Kenya and found that both soil N content and organic C were

negatively correlated with *Striga* seed density in the soil. Therefore, from those results, soils with a low C: N ratio, *Striga* seed density would be significantly lower than where the C: N ratio is high.

A good supply of N in the soil is a good way of *Striga* control. A study done by Schulz *et al*., (2002) in Nigeria showed that nitrogen fertilizer reduced the severity of *Striga* attack as the soil N content gradually increased. Ayongwa (2011) confirmed this and found that roots with an increased N content led to a reduction of *Striga* germination.Moreover the study showed proof of a strong correlation between germination stimulants from the roots and the level of N in the roots.

Some studies indicate that increased use of fertilizer should not have a direct link to *Striga* control, though it has other benefits. Berner *et al*., (1995); Van Mourik (2007) found that application of 2 tons/ha, organic manure did not have a significant effect on *Striga* seed production and long-term effect on *Striga* seed bank. However, Kudra *et al*., (2014) on the other hands found that chicken manure delayed *Striga* emergence on sorghum at a rate of 2.5 t/ha than farmyard manure at a rate of 5.9 t/ha. However a study done by Ikie *et al*., (2007) showed that plots treated with poultry manure had significant higher *Striga* emergence than those with urea treated and the untreated control plots. Therefore, the findings of Ikie *et al*., (2007); Kudra *et al*., (2014) proved that urea had a greater reduction of *Striga* emergence and attachment than chicken manure or farmyard manure.

Despite the observed benefit of higher nitrogen fertilization roles in protecting the crop against *Striga*, it is still not clearof theeconomic viability of nitrogen fertilizer

rates on improving soil fertility, stimulating crop growth and yield while exhausting *Striga* population. Therefore, based on the reviewed literature on the correlation between *Striga* seed bank and soil fertility on crop yield sustainability, there is a need of examining the effect of urea fertilizer on growth, yield and economic returns of sorghum in the semi- arid environment of Tanzania so as to provide detailed and researched valid answers to farmers.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Areas

The study involved two experiments at two different sites, where as one on-farm study was conducted at Ngamu village in Singida Rural District in Singida region and the second, on-station was conducted at Hombolo Research Station, during the 2015-2016 cropping season. Ngamu and Hombolo are located at latitude 6^0 37^1 10^{11}S and longitude 34^0 57^1 5^{11}E, altitude of 1650 m.a.s.l, and latitude 5^0 54^1 29^{11}S and longitude 35^0 57^1 36^{11} E, altitude of 1020 m.a.s.l, respectively.Ngamu and Hombolo are found insemi-arid areas, characterized by erratic and unreliable rainfall with annual mean rainfall of 542.6 and 438.9 mm per annum, respectively and mean annual temperature of 30 to 35.1^0C. The sites also are characterized by unimodal rainfall that extends from November/December to April/May, followed by a long dry season from May to October (TMA, 2014; Kilasara *et al.,* 2015).

3.2 Methodology

This section describes the major approaches that were used in this study. They include soil sampling and laboratory analysis, field experiment, data collection and analysis.

3.2.1 Soil sampling and analysis

Prior to planting, bulk composite soil samples were collected randomly from four different points at each site at a depth of 0-30 cm to include top and sub soils. Sampling was done randomly over the entire soil profile by using a soil auger, spade

and field knife. Each soil portion from each site was thoroughly mixed and reduced to one kg by quartering then air-dried fine earth soil samples and sieved through a 2-mm sieve for laboratory analysis. The fine sieved soil samples were analyzed for physical and chemical properties which included; particle size distribution, soil pH, organic carbon, total nitrogen, extractable phosphorus, exchangeable bases and cation exchange capacityat Sokoine University of Agriculture Soil Laboratory.

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure (Bremner and Mulvaney`s 1982). Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Soil pH was measured potentiometrically in water at the ratio of 1:2.5 soil: water (Mclean, 1986). Extractable P was determined according to the Bray-1 method (Bray and Kurtz, 1945). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) displaced by ammonium acetate extracts were determined by atomic absorption spectrophotometer (Thomas, 1982). Cation exchange capacity of the soil (CECsoil) was determined by using the ammonium acetate saturation method as described by Thomas (1982). Particle size analysis was determined by the Bouyoucos hydrometer method as described by Gee and Bauder`s (1986). Textural class was determined using the USDA textural class triangle (USDA, (1995).

3.2.2 Field experiment

3.2.2.1 Experimental design and treatments

Field plots, 3 m $\times$ 3.2 m, were arranged in a split- plot experimentfitted to randomized complete block design (RCBD) with 4 replications. Adjacent

replications were separated by a 1.5m alley, main plots were separated by a 1m alley and the sub plots were separated by a 0.5 m alley;thus giving the experimental area a total of 1105.5m^2. Treatments in the blocks were assigned in a random manner to avoid biasness. In this research, treatments were six rates of nitrogen (N); 10, 20, 30, 40, 50 and 60 kg N/haand three elite sorghum genotypes (Wahi, Hakika and Pato) adapted to the central zone of Tanzania. The rates of nitrogen served as subplots and the three sorghum varieties as the main plots.

Sorghum genotypes used in this study were early maturing varieties (100 – 120days) namely Wahi, Hakika and Pato obtained from ARI-Hombolo.A susceptible check (Pato) was used for bioassay to evaluate the effect of subsequent rate of nitrogen under *Striga* infestation and performance of the sorghum variety.Urea fertilizer as source of plant nitrogen was collected from fertilizer supplier in Dodoma municipal. The recommended rate of urea (60 kg N/ha) was used as control in this study. The recommended rate (60 kg N/ha) was used as a governor to evaluate the efficacy of reduced rates of N in controlling *Striga* infestation while sustaining or giving more grain yields and economic returns.Each experimental plot had a total of 80 plants, equivalent to 41,667 plants/ha.

3.2.2.2 Crop management

Land preparation was done two weeks before planting and leveling was done by hand hoe. This involved the collection and removal of previous crop residues from the field on which previously crops were cultivated.In Ngamu village the previous crops in the field were Maize and groundnuts while at ARI-Hombolo the previous crop was sorghum.

Sorghum seeds were top- dressed against head smut disease with a copper- based fungicide (Apron star) then planted in a field naturally infested with *Striga asiatica* at ARI-Hombolo and Ngamu village.

Triple superphosphate fertilizer (0:0:46) was applied at planting as a source of phosphorus at the rate of 40 kg P/ha as recommended by Kanyeka, *et al*., (2007). Clean and healthy matured sorghum seeds (varied germination rate) werehand planted at a distance of 0.8 m (inter-row) and 0.3 m (intra-row) with four to six seeds per hole. Sorghum plants were then thinned to two plants per hill at two weeks after planting (WAP).

Urea fertilizer rates were applied once as top dressingat five- leaf stage soon after first weeding (3/1/2016 at Ngamu and 22/1/2016 at Hombolo) and thinning.Throughout the growing season, experimental plotswere kept free of weeds other than *Striga asiatica* using hand hoe and hand pulling methods. Hand hoe weeding was done twice (22/1/2016 and 22/2/2016) at Hombolo research station and at Ngamu village was carried out three times (3/1/2016, 22/1/2016 and 11/2/2016) throughout the season.IMIDA C344SE insecticide was applied once (30/1/2016 in Ngamu and 5/2/2016 in Hombolo) at 0800 h to control insect pest particularly shoot fly, that was seen in the experimental plots.

At Hombolo, overhead irrigation was carried out in March when sorghum attained reproductive stage (from boot stage and after anthesis). Irrigation was carried out due to prolonged drought stress, which could severely affect grain yield. Several findings

have reported on the problem of water stress during reproductive stages as may stop the development of pollen and ovules, prevent fertilization, and induce premature abortion of fertilized ovules (Kramer, 1983; Saini, 1997; Assefa *et al.*, 2010).

3.2.3 Data Collection and Statistical Analysis

3.2.3.1 Data collection

i. **Days to plant emergence** were recorded soon after observing the emergence of plants in a plot.

ii. **Number of plants**in a plot after thinning was carried out at five- leaf stage for calculating of plant damaged.

iii. **Vigor score**on a scale of 1-3, where; 1= very vigorous, 2= average and 3= poor was recorded a week after thinning.

iv. **Days to 50% flowering** were recorded after observing half of plants in the inner two rows have flowered.

v. **Plant damage score** (1-5) whereas; 1= Very high, 2= High, 3= Average, 4= Low and 5= Very low was carried out two weeks after flowering. The score was based on the ratio between the numbers of plants after thinning to the plant stand at flowering. Plant damage was either due to longer duration of dry spells, shoot fly or *Striga* weed. Plant damage score recorded in this study was based only on symptoms due to *Striga* damaged.

vi. **Plant height** (distance from the soil surface to the tip of the panicle, in cm) was measured during the period between half-blooming and hard-dough stages using a 2.5 meter rule.

vii. **Leaf length** (distance from the stem to the tip of the leaf, in cm) and width (distance from one side to the other in the middle third of the leaf, in cm) was measured during the period of booting stage and half blooming by using a 0.3 meter rule. Leaf length and width were used to calculate the leaf area (cm^2) then leaf area index by linear method (Bueno, 1979).

$$LAI = AL/Ag \ (i), \ Also, \ AL= b1LW\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ (ii)$$

Whereby: LAI = Leaf Area Index; AL =Leaf Area; b1 =Sorghum leafregression coefficient factor (0.75); Ag = Ground Area; L = Leaf length (cm) and =Leaf width (cm).

viii. **Days to physiological maturity** were recorded after the sorghum panicle kernels attained physiological maturity.

ix. **Agronomic score** on a scale of 1-5, where1= Very good, 2= Good, 3= Average, 4= Poor and 5= very poor was recorded during the period of physiological maturity. The score was recorded based on the ratio between the numbers of plants after thinning toplants stand at physiological maturity. Plots with higher number of plants at the stage of physiological maturity were assigned a scale of 1 and plots with fewer plants were assigned a scale of 5.

x. **Sorghum shoot biomass,** sampling was done at harvest from an area of one meter square in the two middle rows by cutting the plants at soil surface up to the base of panicle.The collected samples were sun-dried for two weeks then their weight recorded in gram per meter squared.

xi. **Yield and yield components,** sorghum panicles were harvested using knives from the two inner rows (3.84 m^2) excluding the plants that were found at the outer hill from each side of the two rows. The harvested panicles were

collected, counted and packed, labeled and sun-dried to 14% moisture content.

a) **Dry panicle weight (gm)**, sorghum dried panicle were weighed using a beam balance then the panicles were threshed and winnowed for estimation of grain weight in gm pernet plot area harvested (3.84 m^2). Net plot area harvested in this study (3.84 m^2 out of 9.6 m^2) was obtained between the two middle rows while excluding plants that were found at the two outer holes from each side of the two middle rows.

b) **Grain weight (gm),** the threshed grain was weighed using a beam balance and recorded as gm per 3.84 m^2. The grain weight obtained was used to calculate yield (kg/ha) using a formula,

Grain yield (kg/ha) = [(plot yield (kg) $\times$10,000)] / [(number of harvested panicles $\times$ plot size in square meters)]. The latter was converted to tones per hectare………………………………………………………………… (iii).

c) **100 grain weight (gm),** 100 grains were counted and measured by using an automatic electronic balance and recorded asgm per (3.84 m^2)

xii.   *Striga* **shoot counts** were done weekly in each subplot treatmenton a 1$\times$1 m quadrat after *Striga* emergence. Prior to statistical analysis, the values for *Striga* shoot counts were square root $(X + 0.5)^{1/2}$ transformed to normalized data (Gomez and Gomez, 1984) using Microsoft excel.

xiii.   **Total dry weight of *Striga* plants/m^2** was determined by harvesting (30/04/2016 at Ngamu and 25/05/2016 at ARI-Hombolo) all *Striga* plants in an area of onemeter squared and packed separately in paper envelopes then

air-driedfor a week.The dried *Striga* shoots were measured by using an automatic electronic balance and recorded as gm per m^2.

xiv. **Days to*Striga* flowering** were recorded daily soon after observing the first *Striga* flower.

 xv. **Economic returns analysis**, the returns of *Striga* controls were projected over the long-term, from 2010 to 2030, using an economic impact model (Alston *et al*., 2010). Justification of the economic returns was given by the aggregate benefits generated by *Striga* control; less the sum of increased production costs required by *Striga* control and external investment costs (Kryabill and Michael 2009; Kuboja and Temu 2013). The total production cost in this study was incurred for fertilizer, pesticides, weeding, bird scaring, harvesting, threshing and winnowing. There was additional cost at Ngamu for land preparation and hired farmer`s field. At Hombolo addition cost during sorghum production included time for irrigation and cost of fuel used for the irrigation pump.The cost of sorghum production was based on the market price of the area.The price of grain sorghum used was that offered at Singida and Dodoma markets. The equation for computing gross margin was asshown below;

$$ER = (TR\text{-} TC)/ ha\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(iv)}$$

Whereas: ER= Economic returns; TR= Total revenue, TC= Total variable cost and ha= hectare.

To examine the economic implications of alternate *Striga* control methods, furthereconomic analyses were conducted to calculate the cost-benefit ratio, the

marginal rate of return (MRR). The procedure for computing MRR was the one

given by Perrin *et al.* (1988) as shown below;

MRR= (NRi- NRo)/ (Ci- Co)……………...………………………………. (v)

Where;

NRo = Net Revenue for Control Treatment (60 kg N/ha)

NRi = Net Revenue for Treatments i (i= 1,2,3,4, 5)

Co = Total Variable Costs for Control Treatment (60 kg N/ha)

Ci = Total Variable Costs for Treatment i = (i = 1,2,3,4, 5)

3.2.3.2 Statistical data analysis

The data collected were subjected to analysis of variance (ANOVA) using the

GenStat Discovery 14th edition computer software at 5% level of significance.

Treatment mean comparisons were done using the Duncan`s multiple range test

(Gomez and Gomez, 1984). Correlation analyses between *Striga* shootscounts and

physio-chemical characteristics of the soils were done using GenStat software

package (Version 14) in order to eliminate multicollinearity between the identified

variables, which were significantly correlated (correlation coefficient, $r \geq 0.5$) using

principal component analysis. A general equation for the analysis was given by:

$Y_{hij} = T + K_h + A_i + E^z_{i\,(h)} + B_j + (AB)_{ij} + E^s_{j(hi)}.$

Where:

Y_{hij} = general mean common to all observations; T= Treatment mean; K_h= effect due

to replication; A_i= effect due to plant nutrients rates; Bj= effects of varieties to be

tested; $(AB)_{ij}$= interaction effects of plant nutrients rates and three sorghum

genotypes that were tested; and two kinds of errors: $E^z_{i\,(h)}$ = random error effect due

to main plot and $E^s_{j(hi)}$ = random error effect due to split-plots and random noises.

CHAPTER FOUR

4.0 RESULTS

4.1 Temperature and Rainfall Distribution

The monthly rainfall for the 2015/16 crop season is shown in (fig. 1). The rainy period started in November and ended in May 2016. However, good rainfall distribution was observed between January and April and then tapered in May 2016. The total precipitation for that year was typical for the arid regions of central Tanzania; the total rainfall was 762.7 mm and 820.5 mm for Hombolo (Dodoma municipality) and Ngamu (Singida District), respectively (Stephene, S. Z. personal communication, 2016). On the other hand, as shown in (fig. 2), the mean monthly temperature ranged from 28.3-33 ^{0}C and 26.1-28.7 ^{0}C for Hombolo and Ngamu, respectively (Stephene, S. Z. personal communication, 2016).
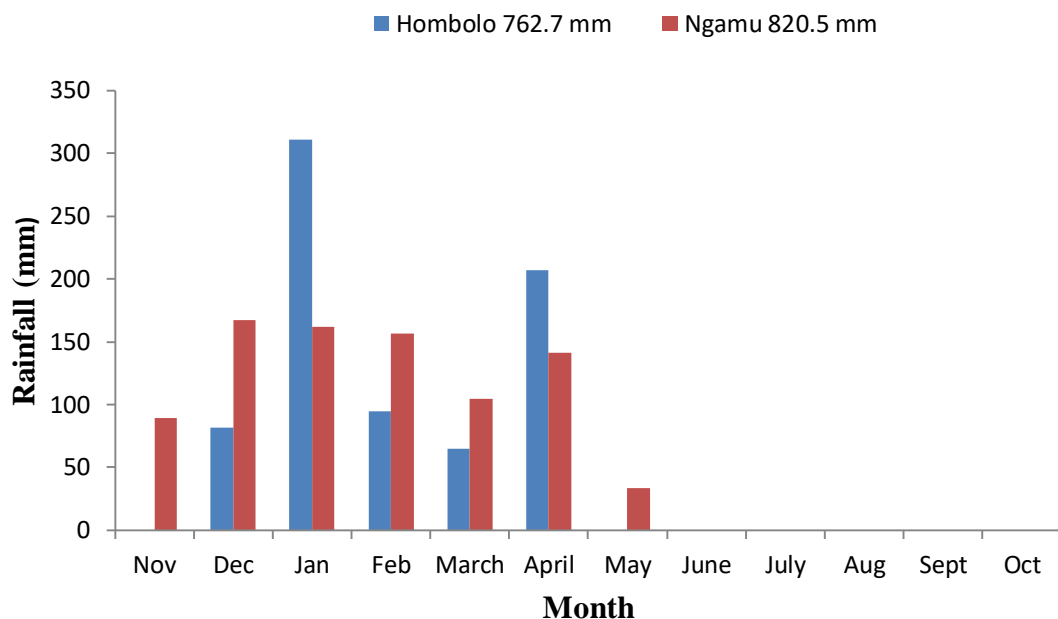
Figure 1: Mean monthly rainfall for 2015-2016 cropping season.
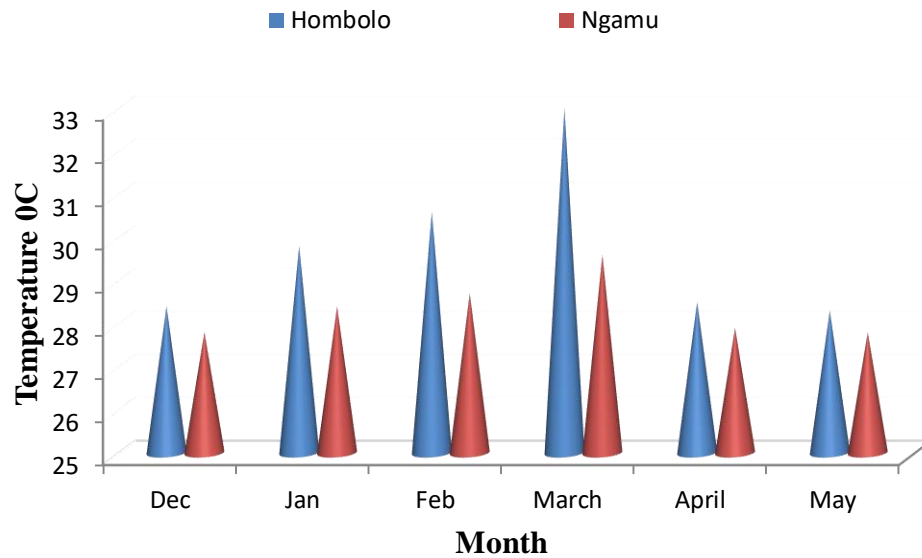
Figure 2: Mean monthly temperature for 2015-2016 cropping season.

4.2 Physical and Chemical Properties at the Experimental Sites

At the time of setting the experiment, total soil N, organic carbon (C) and C/N ratio contents indicated that the soils were degraded and had poor nutrient status except for extractable phosphorus (P), K^+, Mg^{++} and soil pH (Table 1). Therefore based on the differences on cation exchange capacity (CEC), base saturation and calcium contents between Ngamu and Hombolo, soils were more degraded over that of Hombolo.

Table 1: **Chemical and physical properties of the soil samples from the experimental areas**

Soil properties	Hombolo	Rating	Ngamu	Rating
Soil pH	6.04	Medium	6.51	Medium
C (%)	0.459	Very low	0.19	Very low
Total N (%)	0.09	Very low	0.08	Very low
C:N	5.04	Very low	2.38	Very low
Ext P (Mg/Kg)	15.1	Medium	35.2	Medium
CEC (Cmol/Kg)	9	Low	18.2	Medium
Ca^{++} (Cmol/Kg)	2.46	low	5.84	Medium
Mg^{++} (Cmol/Kg)	0.85	Medium	2.9	High
Na^+ (Cmol/Kg)	0.14	Low	0.28	Low
K^+ (Cmol/Kg)	0.83	High	0.88	High
Base saturation (%)	47.6	Low	54.4	Medium
Particle size distribution				
(%) Sand	66		61	
(%) Clay	30		36	
(%) Silt	4		3	
Textural class	Sandy clay		Sandy clay	

*The rating of the soil parameters was according to Landon (1991).

* C= Organic Carbon, N= Nitrogen, P= Phosphorus, CEC= Cation exchange capacity, Ca= Calcium, Mg= Magnesium, Na= Sodium and K= Potassium.

4.3 Days to Emergence of Sorghum, Plant Stand After Thinning and Vigor Score.

In both locations, seedling emergenceamong the varieties evaluated under *Striga* infestation ranged from 68-98% (Table 2).However, the results showed no significant differences in sorghum seedlings emergence, stand after thinning and vigor score between treatments in both locations (Table 2).

Although statistical data showed no differences in seedlings emergence, stand after thinning and plant vigor score across the locations and between the treatments, there was a higher performance in terms of seedling emergence in Hombolo by 7 days and 6 days in Ngamu (Table 2).

Table 2: Effect of sorghum genotypes on days to emergence, plant stand after thinning and vigor score.

Site	Hombolo			Ngamu		
Variables	Days to emergence	Stand after thinning	Plant vigor score	Days to emergence	Stand after thinning	Plant vigor score
A) Sorghum varieties						
Wahi	6a	37a	1a	5a	39a	2a
Hakika	7a	32a	2a	5a	27a	1a
Pato	6a	37a	1a	6a	39a	1a
CV (%)	6.6	13.1	24.2	7.2	7.6	25.4
B) F-STAT						
Sorghum varieties	***	***	*	***	***	***
Replication	ns	*	ns	ns	***	ns
Interaction	ns	ns	*	ns	***	ns

Means followed by different letters are statistically different from each other (p≤0.05) according to Duncan New Multiple Range test.

Key: Significant levels**: ns:** Non significant, **p≤ 5%:** Significant (*), **p≤ 1%:** Very significant (**), **p≤ 0.1%:** Very highly significant (***)

4.4 Effect of Rates of N on Growth and Development of Sorghum

The parameters are reported as days to 50% flowering, sorghum plant height, leaf area index, days to maturity, agronomic score, plant stand at harvest and sorghum shoot biomass.

4.4.1 Days to 50% flowering

The response of sorghum varieties to different rates of urea fertilizer was significant ($P < 0.05$) at 50 % flowering stage across all locations and between the treatments.

At Hombolo, reduced rates of urea by 10 % from the recommended rate (60 Kg N/ha) increased the days to 50 % flowering in sorghum marginally (6%). The maximum days to 50 % flowering were observed at30 Kg N/ha with mean days to 50 % floweringof 85 days followed by 10 Kg N/ha (83 days),20 Kg N/ha (80 days), 40 Kg N/ha and 50 Kg N/ha both with 79 days (Fig. 3). Minimum days to 50 % flowering was recorded at 60 Kg N/ha with 78 days (Fig. 3).Sorghum genotypes differedsignificantly ($P < 0.05$) on the days to 50 % flowering. Hakika variety had significant lower number of days to 50 % flowering (73) followed by Wahi (82) and Pato (88) (Fig. 3).

At Ngamu, longest time to 50 % flowering was observed with 40 Kg N/ha (74 days) followed by 10 Kg N/ha, 20 Kg N/ha, 30 Kg N/ha and 60 Kg N/ha both with 73 days (Fig. 4). Shortest time to 50 % flowering was observed with50 Kg N/ha with (72 days) (Fig. 4). Sorghum genotypes differed significantly ($P < 0.05$) on days to 50 % flowering.Varieties, Wahi and Hakika had fewer days to 50 % flowering (73days) followed by variety Pato (74 days) (Fig.4).

The interaction effect between urea fertilizer rates and sorghum genotypes at both sites did not differ significantly ($P < 0.05$) in terms of days to 50 % flowering.

Figure 3: Effect of fertilizer rates on days to 50% flowering in sorghum at Hombolo.
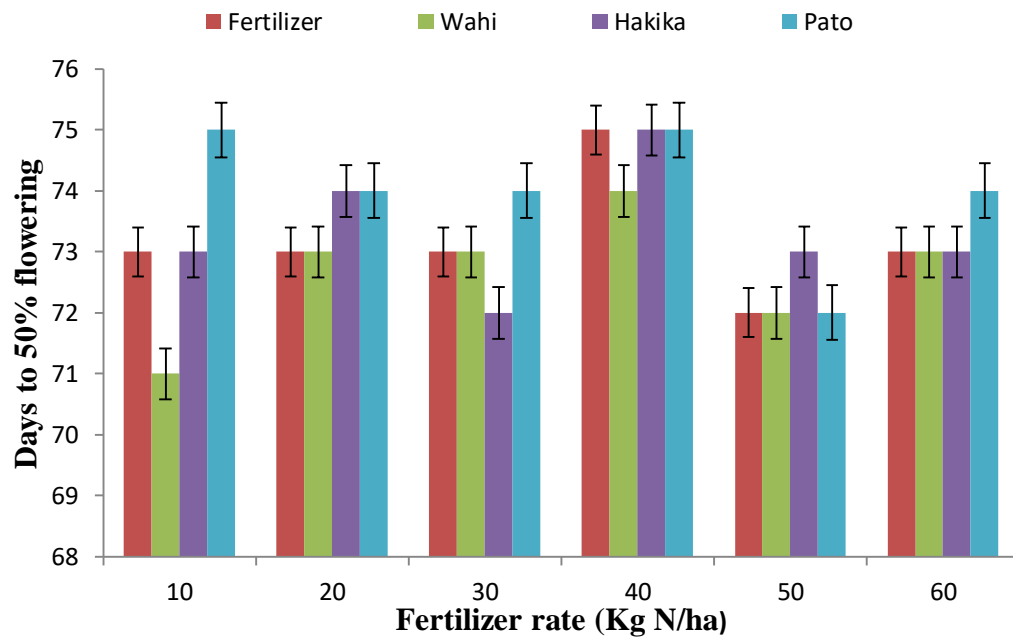
Figure 4: Effect of fertilizer rates on days to 50% flowering in sorghum at Ngamu.

4.4.2 Plant height

Plant height varied among the urea fertilizer rates and locations. At both locations, there were significant ($P < 0.05$) differences in plant height.

At Hombolo, application of 60 Kg N/ha gave tallest plants with a mean of 135.8cm (Fig.5).Minimum plant height (113.2 cm) was recorded when 30 Kg N/ha was applied (Fig. 5). Sorghum genotypes differed significantly ($P < 0.05$) in terms of plant height. Sorghum variety, Pato had significant ($P < 0.05$) taller plants (137.2 cm) followed by Wahi (124.3cm) and Hakika (98.3cm) (Fig. 5).

At Ngamu, maximum plant height was observed with 60 Kg N/ha (163.37 cm). Sorghum genotypes supplied with 10 Kg N/ha were significantly ($P < 0.05$) shorter (155.98 cm) than those with 20 Kg N/ha (156.13 cm), 30 Kg N/ha (156.24), 40 Kg N/ha (159.36 cm) and 50 Kg N/ha (161.94 cm) (Fig. 6). Plants of Pato variety were significantly ($P < 0.05$) taller (185.56 cm) followed by Wahi (165.65 cm) and Hakika (125.30 cm) (Fig. 6).

The interaction effect among urea fertilizer rates and sorghum genotypes at both sites did not differ significantly ($P < 0.05$) on plant height (cm).

Figure 5: Effect of fertilizer rateson plant height (cm) in sorghum at Hombolo.
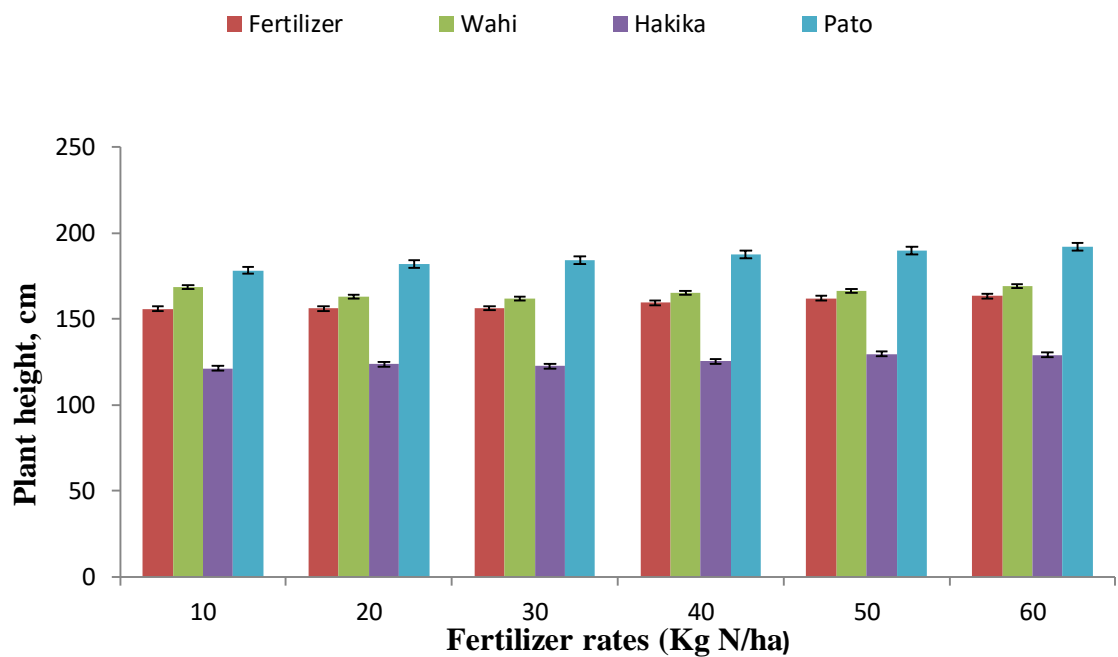
Figure 6: Effect of fertilizer rates on plant height (cm) in sorghum at Ngamu.

4.4.3 Leaf area index

The data on the effect of different rates of urea fertilizer on LAI are shown on Fig. 7. Different rates of urea fertilizer and locations had significant ($P < 0.05$) influence on LAI at phenological stages of the sorghum plant.

At Hombolo, maximum leaf area index was observed at the rate of 60 Kg N/ha with a mean leaf area index 0.15. The minimum leaf area index was observed at the rates of 30, 20 and 10 Kg N/ha with a mean leaf area index 0.12 (Fig. 7). Plants of sorghum varieties Hakika had lower leaf area index with a mean leaf area index 0.12followed by Wahi and Pato varieties both with a mean leaf area index 0.13.

At Ngamu, reduced rates of urea by 10 % application from the recommended rate (60 Kg N/ha) did not reduce/or increase the leaf area index (i.e. both rates have a mean leaf area index 0.03) as shown in (Fig.7). Furthermore, both sorghum varieties (Wahi, Hakika and Pato) had the same mean leaf area index about 0.03.
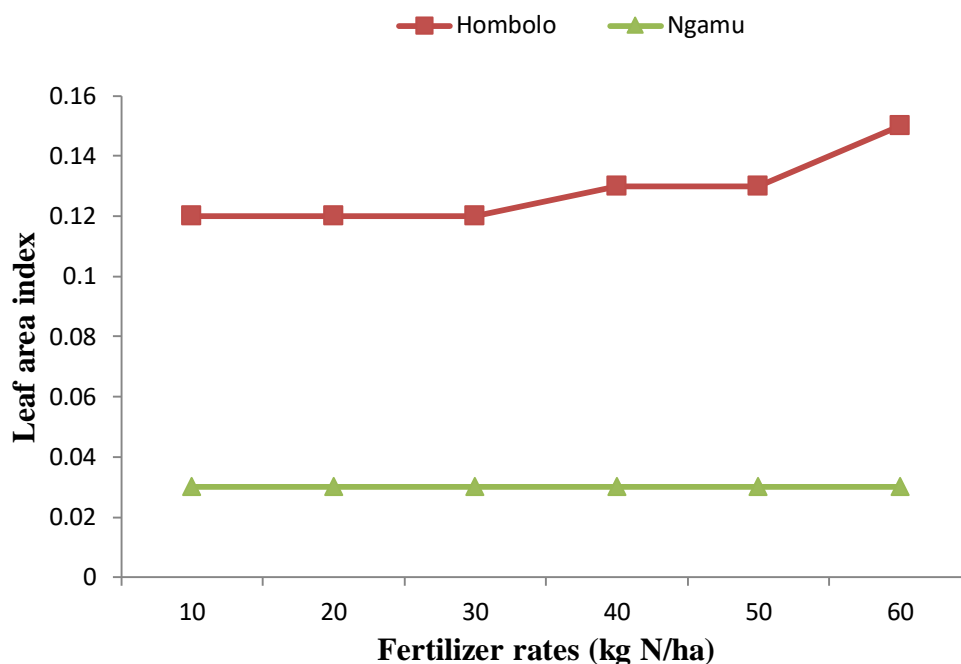
Figure 7: Effect of fertilizer rates and location on leaf area index in sorghum.

The interaction effect between urea fertilizer rates and sorghum genotypes at Hombolo had significant ($P < 0.05$) effects on the leaf area index (Fig. 8).
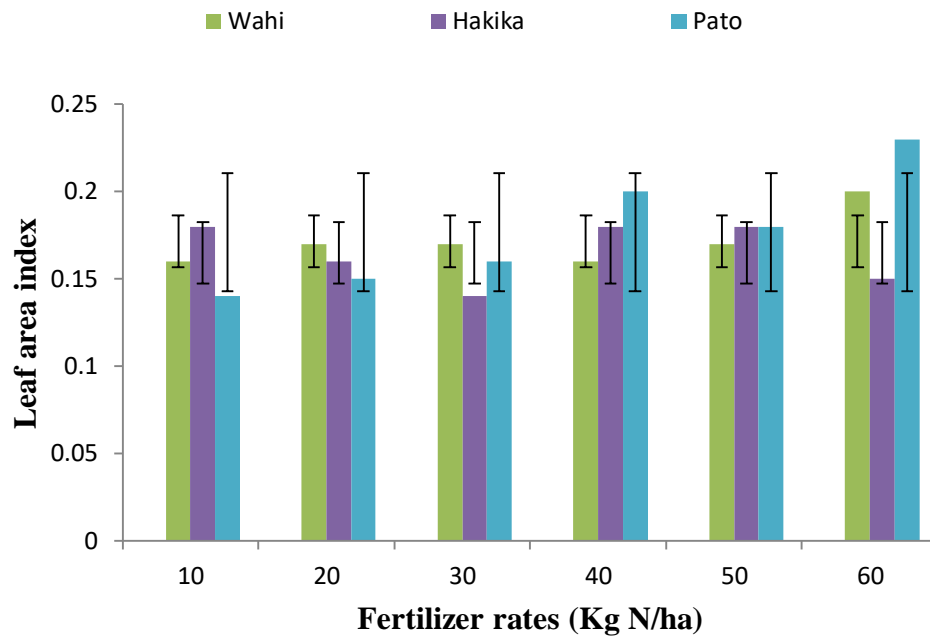
Figure 8: Effect of fertilizer rates on interaction of leaf area index in sorghum at Hombolo.

4.4.4 Days to physiological maturity

Days to physiological maturity varied among urea fertilizer rates and locations. At both locations, there were significant ($P < 0.05$) differences of days to physiological maturity among treatments.

At Hombolo, longest time to physiological maturity was observed at 50 N, 30N and 10 Kg N/haboth with 109 days (Fig. 9). The shortest time to physiological maturity was recorded at 20 Kg N/ha, 40 Kg N/ha and 60 Kg N/ha both with mean days to

physiological maturity 107 days (Fig.9). Sorghum genotypes differed significantly ($P < 0.05$) on the days to maturity. Variety Hakika had significantly lower days to physiological maturity with a mean of 103 days followed by Wahi (108 days) and Pato (114 days) (Fig. 9).

At Ngamu, maximum days to maturity were observed at 60 Kg N/ha and 20 Kg N/ha both with mean days to physiological maturity (104 days). 50 Kg N/ha, 40 Kg N/ha, 30 Kg N/ha and 10 Kg N/ha had significant fewer days to maturityboth with mean 103 days (Fig.10). Sorghum genotypes, Wahi and Hakika had significantly ($P < 0.05$) fewer days to maturity both with103days followed Pato (105 days) (Fig 10).
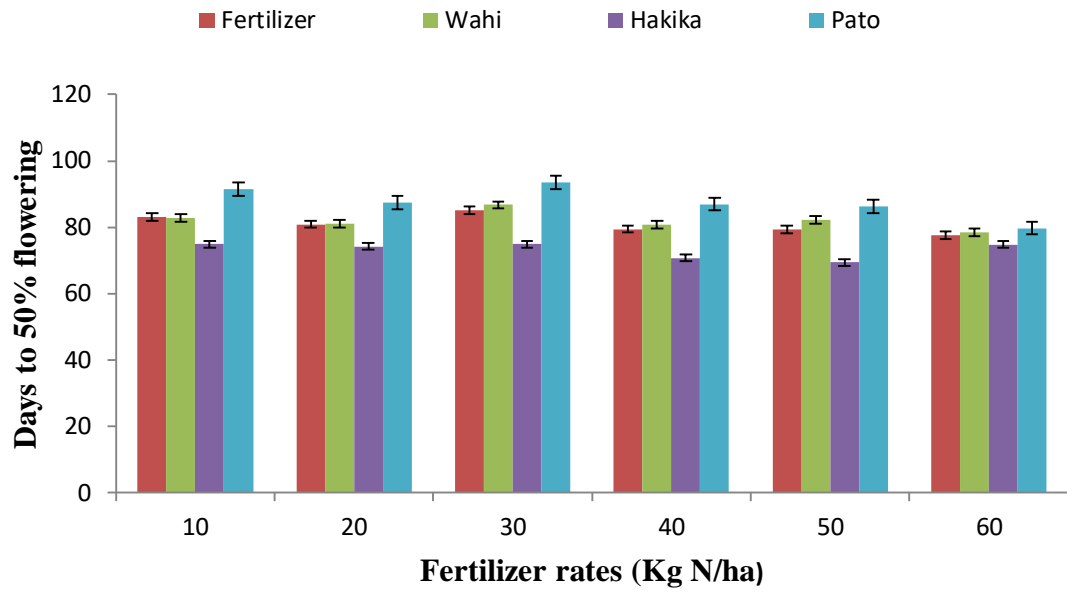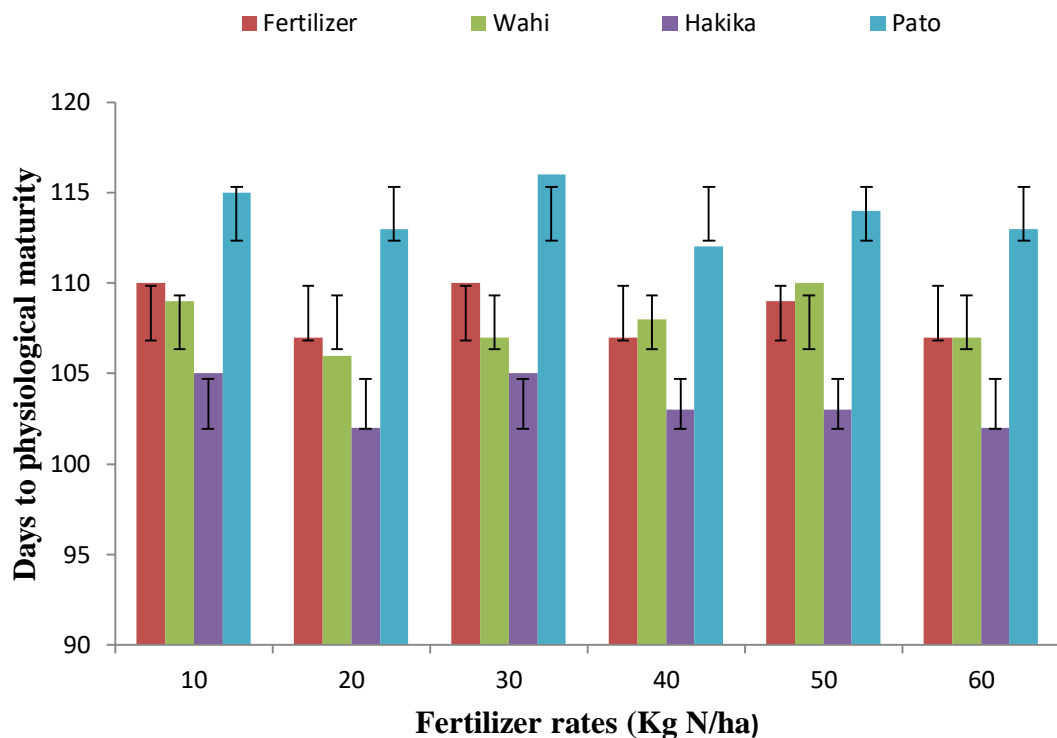

Figure 9: Effect of fertilizer rates on days to maturity in sorghum at Hombolo.
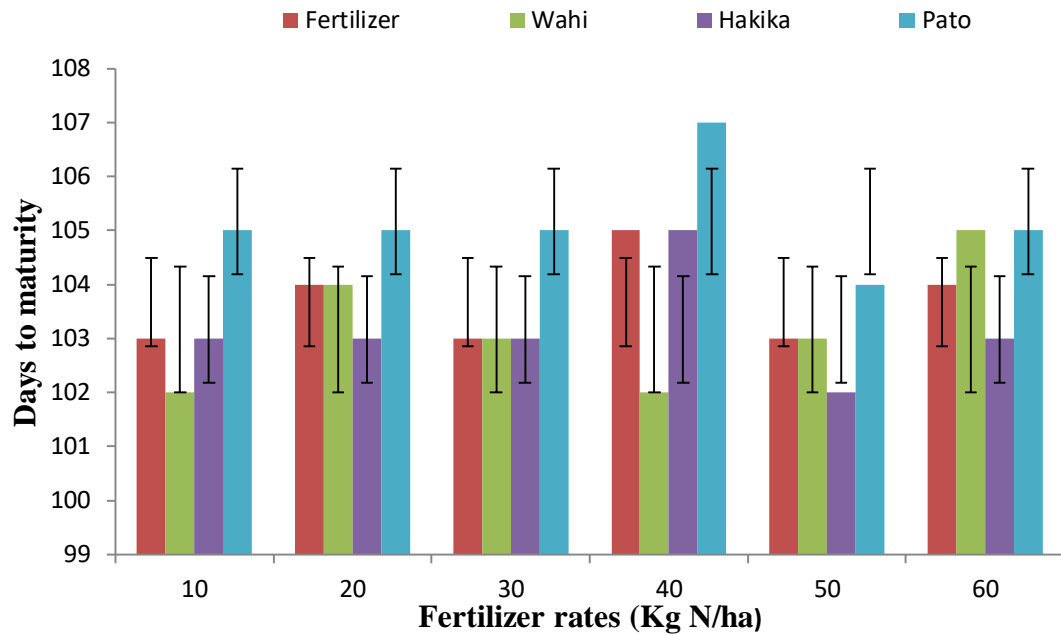
Figure 10: Effect of fertilizer rates on days to maturity in sorghum at Ngamu.

4.4.5 Agronomic score

Agronomic score varied among urea fertilizer rates and locations.At both locations, agronomic score differed significantly (p=0.05) among treatments at physiological maturity stage.

At Hombolo, the highest agronomic score (1) was attained with 60 kg N/ha and 20 kg N/ha. The minimum agronomic score (2) was observed at the rate of 10 kg N/ha, 30 kg N/ha, 40 kg N/ha and 50 kg N/ha (Fig. 11). All sorghum genotypes, Hakika, Wahi and Pato had agronomic score with a mean score of 2 (Fig 11).

At Ngamu, the maximum agronomic score was attained with60 kg N/ha and 10 kg N/ha with a mean score of 1. The minimum agronomic score was observed with50 kg N/ha, 40 kg N/ha, 30 kg N/ha and 20 kg N/ha all with a mean score of 2 (Fig. 12). Sorghum variety, Hakika had significantly lower agronomic score (2) followed by Pato and Wahi, both with a mean score of 1 (Fig. 12).
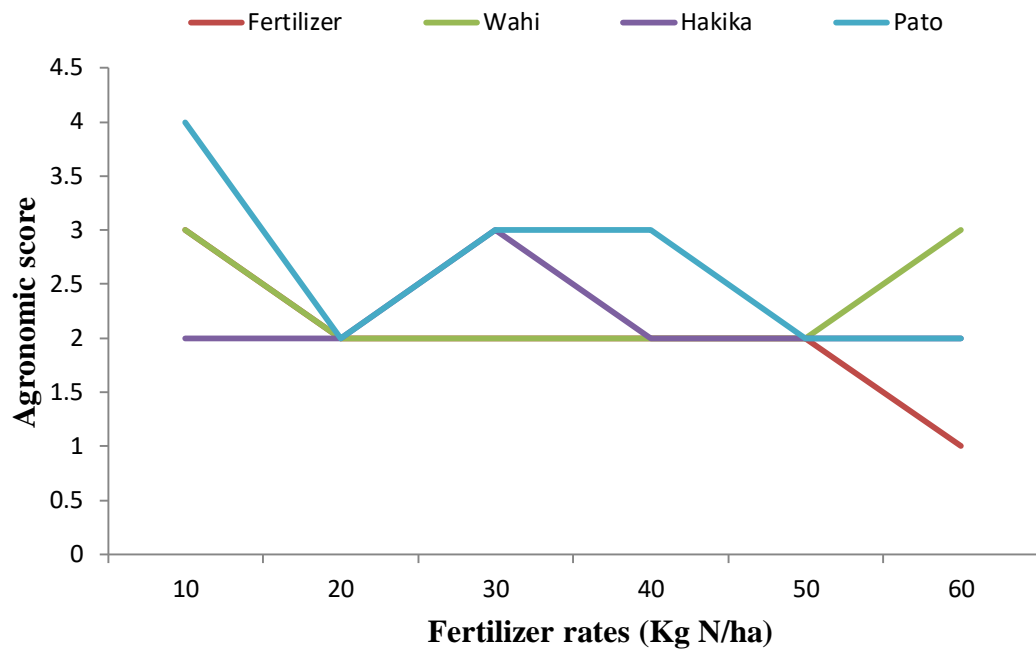
Figure 11: Effect of fertilizer rates on agronomic score in sorghum at Hombolo.
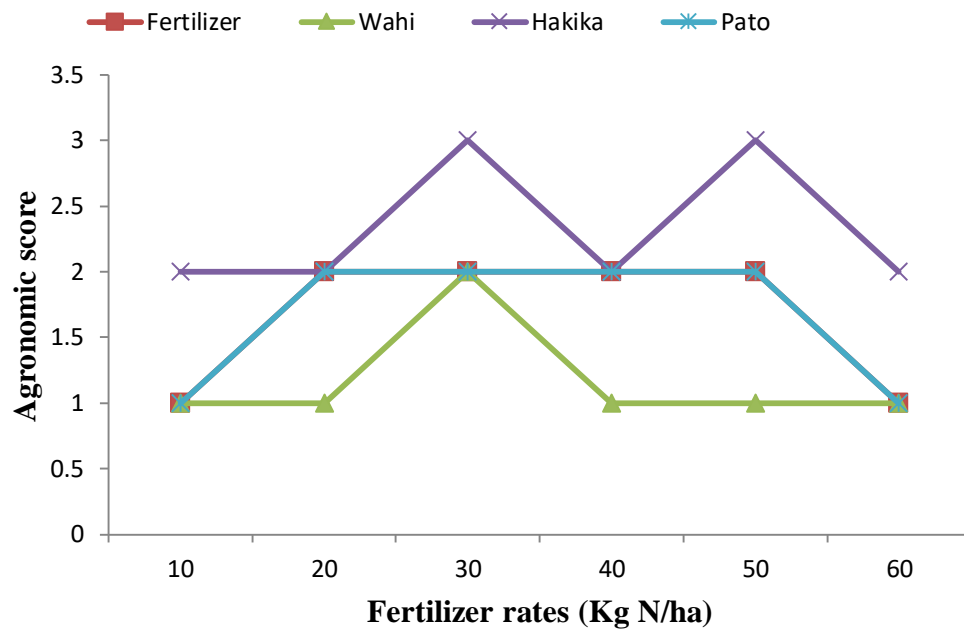
Figure 12: Effect of fertilizer rates on agronomic score in sorghum at Ngamu.

4.4.6 Plant damage

Sorghum plants performance varied between urea fertilizer rates and locations. At Hombolo, there were significant ($P < 0.05$) differences of plant damage among treatments and at Ngamu no significant ($P < 0.05$) differences of plant damage for Hakika variety was recorded.

At Hombolo, when urea fertilizer was applied, the highest plant damage score (3) was recorded when sorghum varieties were applied with 60 kg N/ha followed by 30 kg N/ha, 40 kg N/ha and 50 kg N/ha all with mean plant damage score (4). The lowest plant damage score (5) was recorded when sorghum varieties were applied with 10 kg N/ha and 20 kg N/ha (Fig. 13). Hakika variety had significantly ($P < 0.05$) lower plant damage score (4) than Pato and Wahi both with mean plant damage score (3) (Fig. 13).

At Ngamu, when urea fertilizer was applied, sorghum varieties with 30 kgN/ha weresignificant ($P < 0.05$) higher plant damage score (1) than 10 kg N/ha, 20 kg N/ha, 40 kg N/ha, 50 kg N/ha and 60 kg N/ha all with plant damage score of 2(Fig. 14).Pato variety had significantly lower plant damage score (3) than Wahi (2) and Hakika (1) (Fig. 14).
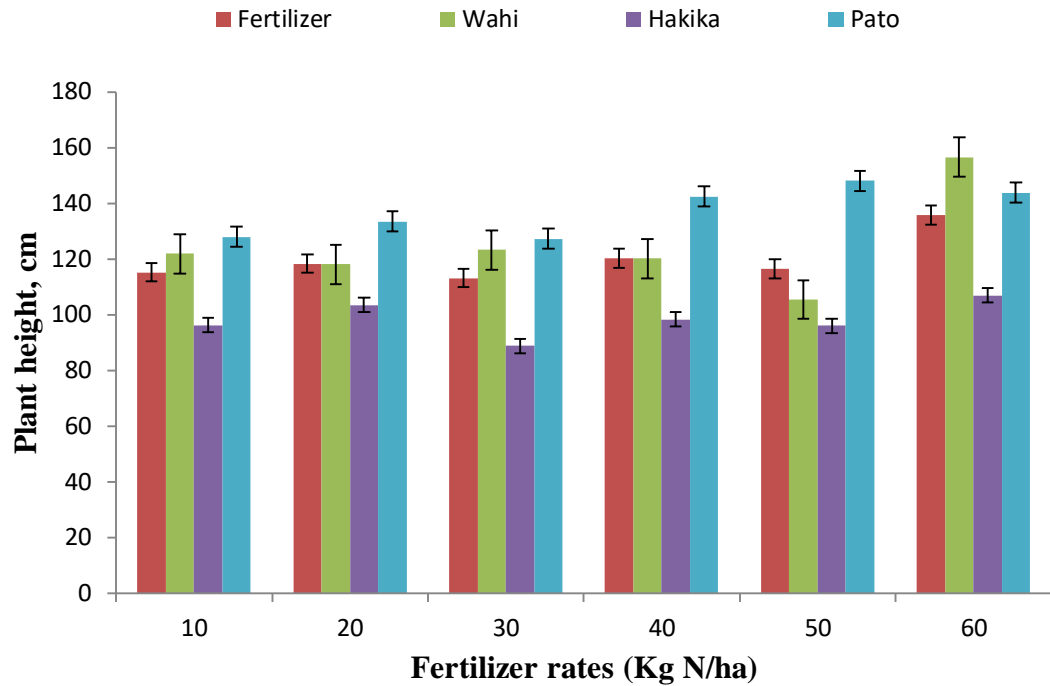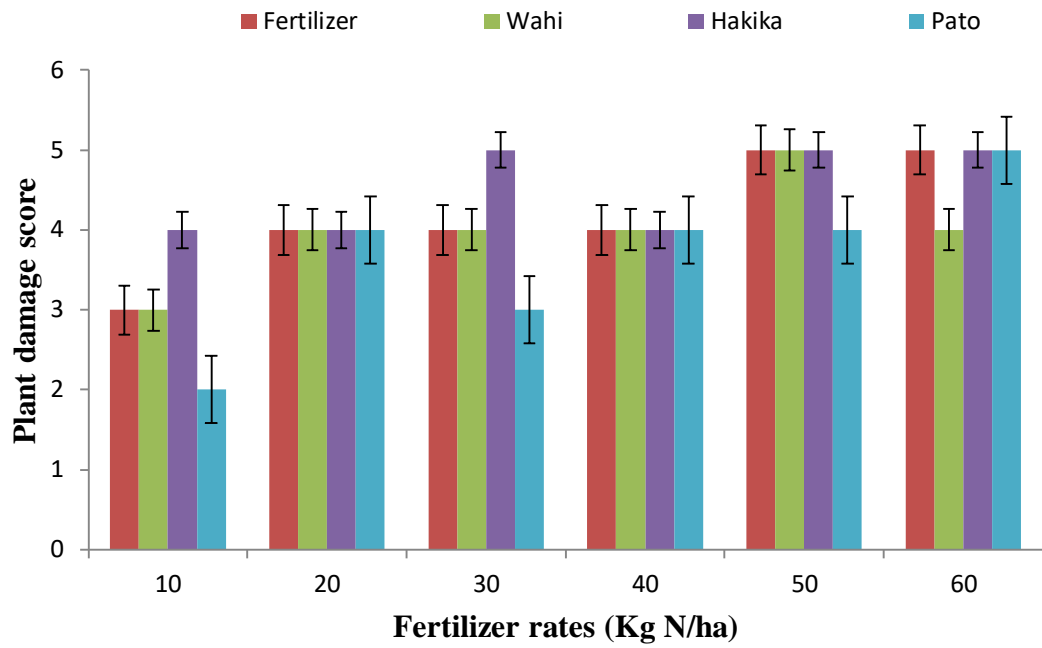
Figure 13: Effect of fertilizer rates on plant damage in sorghum at Hombolo.
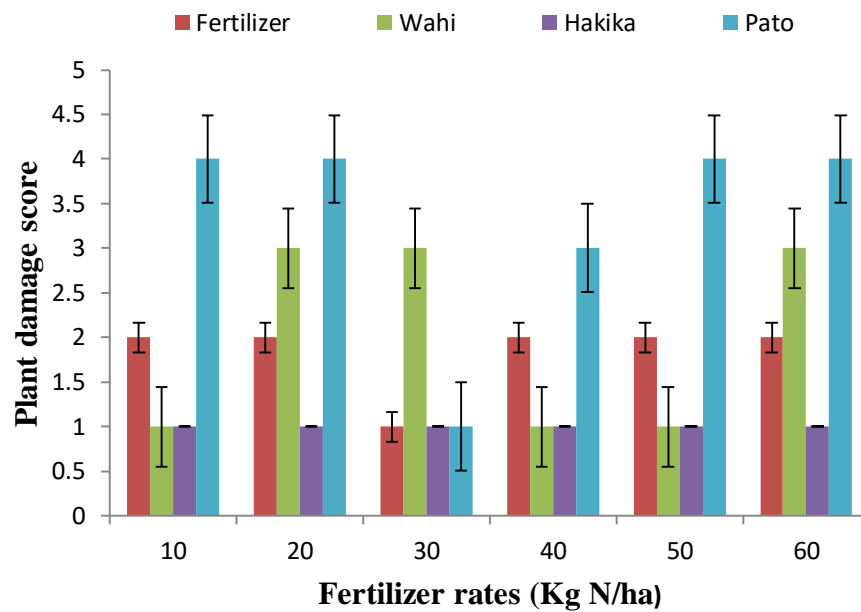
Figure 14: Effect of fertilizer rates on plant damage in sorghum at Ngamu.

4.4.7 Plant stands at harvest

The responses of sorghum plant stands at harvest under six rates of N were significantly different (p <0.05) in all locations.

At Hombolo, the maximum plant stands at harvest were attained at the rate of 20 Kg N/ha with 30 plants followed by 50 Kg N/ha (29 plants), 60 Kg N/ha and 40 Kg N/ha both with 28 plants (Fig. 15). The minimum number of plant stands at harvest were observed at 10 Kg N/ha (23 plants) and 30 Kg N/ha (27 plants) (Fig.15). Sorghum variety Wahi had significant higher plant stand at harvest with 30 plants followed by Pato (27 plants) and Hakika (26 plants) (Fig. 15).

At Ngamu, the maximum plant stands at harvest were attained at the rate of 60 Kg N/ha with 38 plants followed by 10 N (37 plants), 40 N (36 plants), 50 N and 20 Kg N/ha all with 34 plants (Fig. 16). The minimum plant stands at harvest was observed with the rate of 30 Kg N/ha (32 plants) (Fig.16). Sorghum genotypes had significant ($P < 0.05$) effects on plant stands. Varieties Wahi and Pato had significantly higher plant stands at harvest with 39 plants followed Hakika (26 plants) (Fig 16).
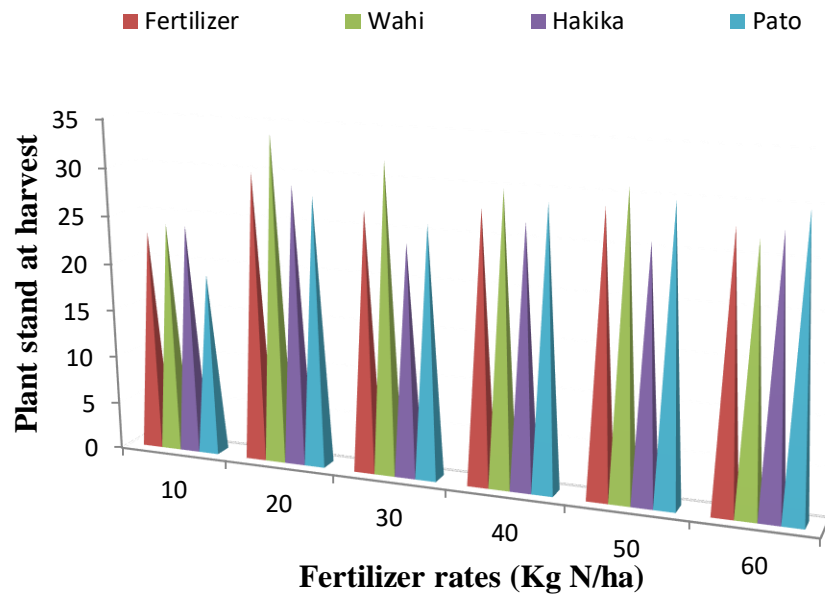
Figure 15: Effect of fertilizer rateson plant stand at harvest in sorghum at Hombolo.
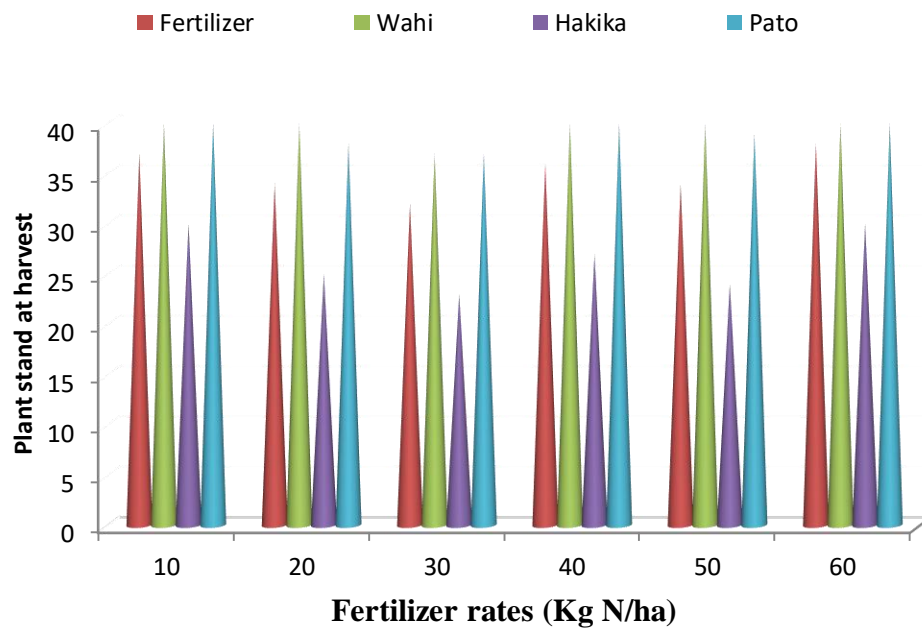
Figure 16: Effect of fertilizer rates on plant stand at harvest in sorghum at Ngamu.

4.4.8 Sorghum plant biomass (g/m^2)

The result showed that, at Ngamu when sorghum is grown under low *Striga* infestation, it generates more biomass than when it is grown under high infestation (Hombolo) (Fig.18).In both locations, the responses of sorghum biomass to six rates of urea fertilizer were significantly different (p < 0.05).

At Hombolo, the highest plant biomass (805 g/m$^{2)}$was recorded from sorghum treated with50 Kg N/hafollowed by 60 N (794 g/m^2), 20 N (650 g/m^2), 40 N (623 g/m^2) and 30 Kg N/ha (540 g/m^2) (Fig. 17). The minimum plant biomass was observed at the rate of 10 Kg N/ha with meanplant biomass 502 g/m^2 (Fig.17). Sorghum varieties had significant (P < 0.05) effects on plant biomass (g/m^2). Wahi variety had significantly higher plant biomass with 759 g/m^2 followed by Pato (664 g/m^2) and Hakika (534g/m^2) (Fig. 17).

At Ngamu, the highest sorghum plant biomass (1013.3 g/m^2) was attained with the rate of 60 Kg N/ha followed by 50 N (983.7 g/m^2), 40 N (938.5 g/m^2), 30 N (900.2 g/m^2) and 20 Kg N/ha (757.8 g/m^2) (Fig. 18). The lowest plant biomass was observed with the rate of 10 Kg N/ha (698.9 g/m^2) (Fig.18).Variety Pato had significantly higher plant biomass (1589.9 g/m^2) followed by Hakika (697.9 g/m^2) and Wahi (358.4g/m^2) (Fig. 18)
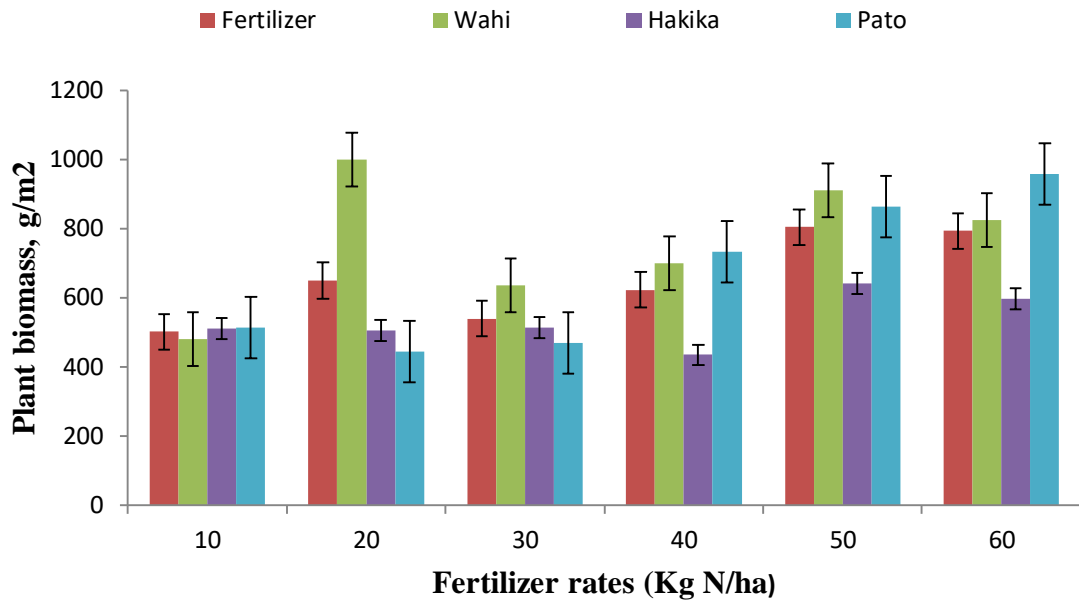
Figure 17: Effect of fertilizer rates on sorghum plant biomass at Hombolo.
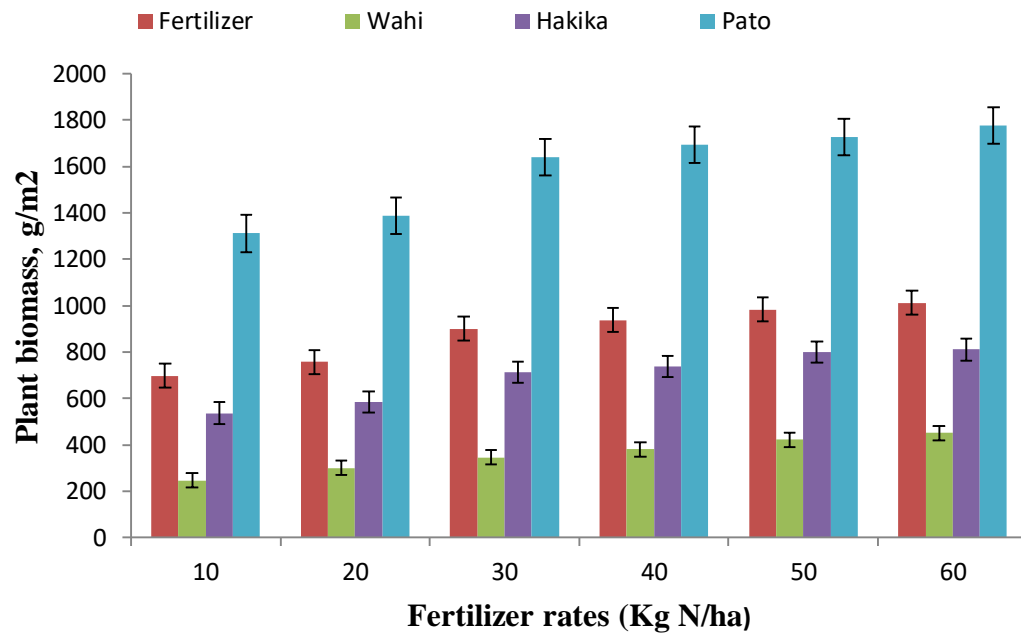
Figure 18: Effect of fertilizer rates on sorghum plant biomass at Ngamu.

4.5 Effect of Rates of N on Sorghum Grain Yield and Yield Components

The responses of all sorghum grain yield variables evaluated under different rates of N were significantly different ($p < 0.05$) among the genotypes planted at Hombolo (Table 3). However for those grown at Ngamu there were no significant differences ($p > 0.05$) in grain weight (gm) and grain yield (t/ha) under different rates of urea fertilizer (Table 3).

4.5.1 Dry panicle weight (gm)

At Hombolo, the highest panicle dry weight was attained at the rate of 60 Kg N/ha with 862 gm followed by 50 N (702 gm), 40 N (701gm), 10 N (590 gm) and 20 Kg N/ha (583 gm) (Table 3). The lowest panicle dry weight was observed at the rate of 30 Kg N/ha with 406 gm. Wahi variety had significantly higher panicle dry weight (662gm) followed by Pato (658gm) and Hakika (603 gm) varieties (Table 3).

At Ngamu, the highest panicle dry weight (3358 gm) was attained when 60 Kg N/ha was applied. The lowest panicle dry weight (2623 gm) was observed when 30 Kg N/ha was applied (Table 3).Variety Pato had significantly higher panicle dry weight (3950gm) followed by Wahi (3021gm) and Hakika (1763 gm). The interaction effect between urea fertilizer rates and sorghum genotypes were significant ($P < 0.05$) on dry panicle weight (Table 3).

4.5.2 Grain weight (gm)

At Hombolo, when 60 Kg N/ha was applied, the grain weight (gm) of the sorghum genotypes was significantly ($P < 0.05$) higher (582 gm) that application of 40 N (498 gm), 50 N (488 gm), 10 N (420 gm) and 20 Kg N/ha (414 gm) (Table 3). The

lowestgrain weight was observed with 30 Kg N/ha (247 gm). Grain weight of Wahi was significantly ($P < 0.05$) higher (491gm) than that of Pato (467gm) and Hakika (368gm) (Table 3).

At Ngamu, application of 50 Kg N/ha attained higher grain weight (2297 gm) than that of 20 N (2042 gm), 30 N (2036 gm), 60 N (2015 gm), 40 N (1995 gm) and 10 Kg N/ha (1879 gm) (Table 3). Pato variety had significantly ($P < 0.05$) higher grain weight (2769gm) thaneither Wahi (2284gm) or Hakika (1078gm) (Table 3).

4.5.3 100 grain weight (gm)

AtHombolo, the highest 100 grain weight (4.06 gm) was attained with30 Kg N/ha followed by 50 N (4.02 gm), 10 N (3.98 gm), 20 N (3.88 gm), 60 N (3.83 gm) or 40 Kg N/ha (3.8 gm) (Table 3). Sorghum genotypes, variety Pato had significantly ($P < 0.05$) higher 100 grain weight (4.41gm) than either Wahi (3.73gm) or Hakika (3.64gm) (Table 3).

At Ngamu, when 30 Kg N/ha was applied, 100 grain weight of sorghum varieties was significantly ($P < 0.05$) higher (4.06 gm) than either 50 N (4.02 gm), 10 N (3.98 gm), 20 N (3.88 gm), 40 N (3.84 gm) or 60 Kg N/ha (3.83 gm) (Table 3). When sorghum genotypeswere supplied with urea fertilizer, 100 grain weight of variety Pato was significantly ($P < 0.05$) higher (4.41gm) than Wahi (3.73gm) and Hakika (3.66gm) (Table 3).

4.5.4 Grain yield (t/ha)

At Hombolo, the highest grain yield (1.52 t/ha) was recorded with 60 Kg N/ha than that of 40 N (1.30 t/ha), 50 N (1.27 t/ha), 10 N (1.09 t/ha), 20 N (1.08 t/ha) and 30 Kg N/ha (0.64 t/ha) (Table 3).The genotype Wahi when supplied with urea fertilizer gave significantly ($P < 0.05$) higher grain yield (1.28 t/ha) thaneither Pato (1.21 t/ha) or Hakika (0.96 t/ha)(Table 3).

AtNgamu, the highest grain yield (5.98 t/ha) was attained with 50 Kg N/ha than that of 20 N (5.32 t/ha), 30 N (5. 3t/ha), 60 N (5.25 t/ha), 40 N (5.2 t/ha) and10 Kg N/ha (4.89 t/ha) (Table 3). Sorghum genotypes, when applied with urea fertilizer, grain yield of Pato variety was significantly ($P < 0.05$) higher (7.21 t/ha) than Wahi (5.95 t/ha) and Hakika (2.81 t/ha) (Table 3).

Table 3: Effect of rates of N on the sorghum grain yield traits at Hombolo and Ngamu village.

Sites	Hombolo				Ngamu			
Variables	Dry Panicle weight	Grain weight	100 grain weight	Grain yield	Dry Panicle weight	Grain weight	100 grain weight	Grain yield
	(gm)	(gm)	(gm)	(t/ha)	(gm)	(gm)	(gm)	(t/ha)
A)Fertilizer rates								
60 Kg N/ha	862c	582c	3.83ab	1.52c	3358b	2015a	3.83a	5.25a
50 Kg N/ha	702bc	488bc	4.02bc	1.27bc	3210b	2297a	4.02ab	5.98a
40 Kg N/ha	701bc	498bc	3.80a	1.3bc	2851a	1995a	3.84a	5.2a
30 Kg N/ha	406a	247a	4.06c	0.64a	2623a	2036a	4.06b	5.3a
20 Kg N/ha	583b	414b	3.88abc	1.08b	2770a	2042a	3.88ab	5.32a
10 Kg N/ha	590ab	420b	3.98abc	1.09b	2657a	1879a	3.98ab	4.89a
B)Sorghum varieties								
Wahi	662	491	3.73	1.28	3021	2284	3.73	5.95
Hakika	603	368	3.64	0.96	1763	1078	3.66	2.81
Pato	658	467	4.41	1.21	3950	2769	4.41	7.21
CV (%)	33.2	34.3	5.8	34.3	12.6	23	5.7	23
C)F-STAT								
Fertilizer rates	***	***	*	***	***	ns	ns	ns
Varieties	ns	*	***	*	***	***	***	***
Interaction	ns	ns	ns	ns	*	ns	ns	ns

Means followed by different letters are statistically different from each other (p≤0.05) according to Duncan New Multiple Range test.
Key: Significant levels**: ns:** Non significant, **p≤ 5%:** Significant (*), **p≤ 1%:** Very significant (**), **p≤ 0.1%:** Very highly significant (***)

4.6 *Striga* Emergence, Days to *Striga* Flowering and Maximum Emerged *Striga* Shoots

In both locations, delayed emergence of *Striga* shootsper m^2 was observed with a rate of 60 Kg N/ha (67days) at Hombolo and 34 daysat Ngamu (Table 4).The maximum days to *Striga* flowering was recorded with 60 Kg N/ha (87 days) (Hombolo) and 52 days (Ngamu). Sorghum genotype also showed discrepancy on days to Striga emergence and flowering. At Hombolo, variety Wahi had significantly ($P < 0.05$) higher days to *Striga* emergence and days to *Striga* flowering than the other genotypes (Table 4). In contrast to Hombolo, the longest time for *Striga* emergence and flowering at Ngamu was recorded with Pato variety (Table 4). Between the study sites, the highest number of emerged *Striga* shoots per m^2 were recorded with 20 Kg N/ha at Hombolo (Table 4). On the other hand, variety Pato had highest emerged *Striga* shoots in both locations (Table 4). However, no differences were observed in the interactions of treatments.

Table 4: *Striga* emergence, days to *Striga* flower and maximum emerged *Striga* shoots.

Variables	Hombolo			Ngamu		
	Days to first *Striga* emergence	Days to first *Striga* flowering	Maximum emerged *Striga* shoots/m^2	Days to first *Striga* emergence	Days to first *Striga* flowering	Maximum emerged *Striga* shoots/m^2
A)Fertilizer						
60 Kg N/ha	67a	87a	3a	79a	88a	1a
50 Kg N/ha	60a	65a	4ab	67a	72a	1a
40 Kg N/ha	63a	70a	3a	68a	74a	1a
30 Kg N/ha	57a	75a	4ab	62a	73a	1a
20 Kg N/ha	57a	79a	6c	64a	80a	1a
10 Kg N/ha	61a	82a	5bc	60a	72a	1a
B)Sorghum						
Wahi	63	84	4	65	74	1
Hakika	59	63	1	71	80	1
Pato	60	80	6	61	75	2
CV (%)	52.3	49.6	43.3	103.9	105.7	35.7
C) F-STAT						
Fertilizer rates	ns	ns	**	ns	ns	ns
Varieties	ns	ns	***	***	***	***
Interaction	ns	ns	ns	ns	ns	ns

Means followed by different letters are statistically different from each other (p≤0.05) according to Duncan New Multiple Range test.
Key: Significant levels**: ns:** Non significant, **p≤ 5%:** Significant (*), **p≤ 1%:** Very significant (**), **p≤ 0.1%:** Very highly significant (***)

4.7 *Striga* Shoots Counts

At Hombolo, fertilizer rates had significant (P ≤ 0.05) effects on *Striga* shoots counts/m^2 at 10 WAP, 11 WAP and at harvest (21 WAP) (Fig. 19). Among all sampling periods, the highest number of *Striga* shoots counts/$m^2$was recorded at 12 WAP (Fig. 19). At 12 WAP, 10 Kg N/ha resulted into highest number of *Striga* shoots counts/m^2 (179). At harvest, application of 20 Nand 10 Kg N/ha resulted intohighest number of *Striga* shoots counts/m^2 with 97 plants/m^2 and 86 plants/m^2, respectively (Fig. 19). At 10 WAP, the lowest number of *Striga* shoots counts/m^2 was recorded with 40 Kg N/ha and the highest number of *Striga* shoots counts/m^2 was recorded with 10 Kg N/ha (Fig. 19). At 11 WAP, the highest number of *Striga* shoots count/m^2 was recorded from 30 N and 10 Kg N/ha treated plots and the lowest *Striga* shoots counts/m^2 was recorded with 40 Kg N/ha (Fig. 19). Reduction of fertilizers had significant (P ≤ 0.05) effects on *Striga* counts/m^2 as there were decrease in *Striga* shoots counts/m^2 with 40 Kg N/ha, except at 12 WAP (Fig. 19). Sorghum genotypes, Pato and Wahi had significantly (P ≤ 0.05) higher *Striga* shoots count/ m^2 at harvest than Hakika (Fig. 20).
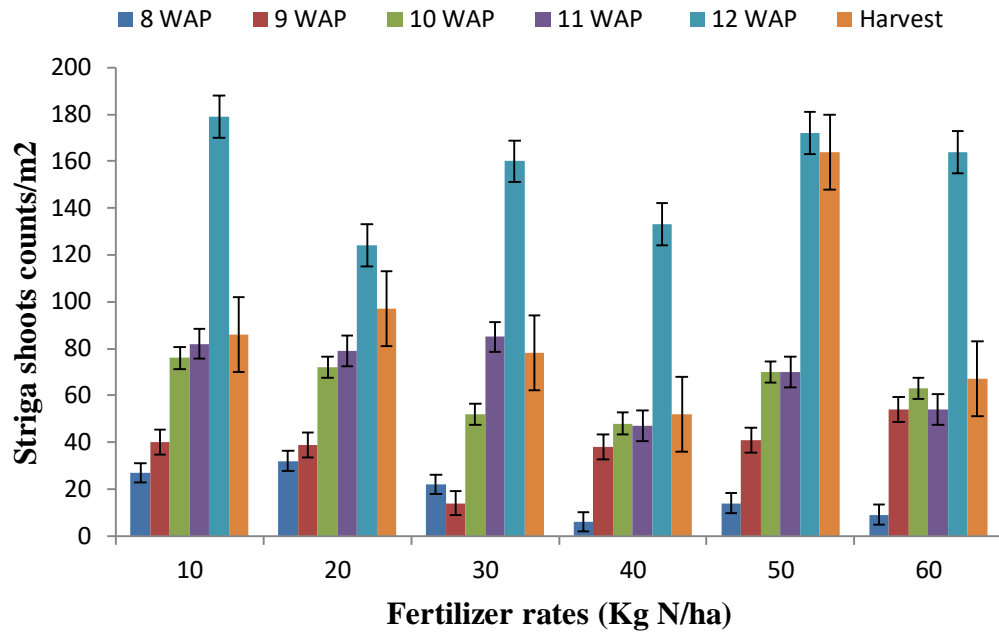
Figure 19: Effect of fertilizer rates on *Striga* shoots counts/m² at Hombolo.
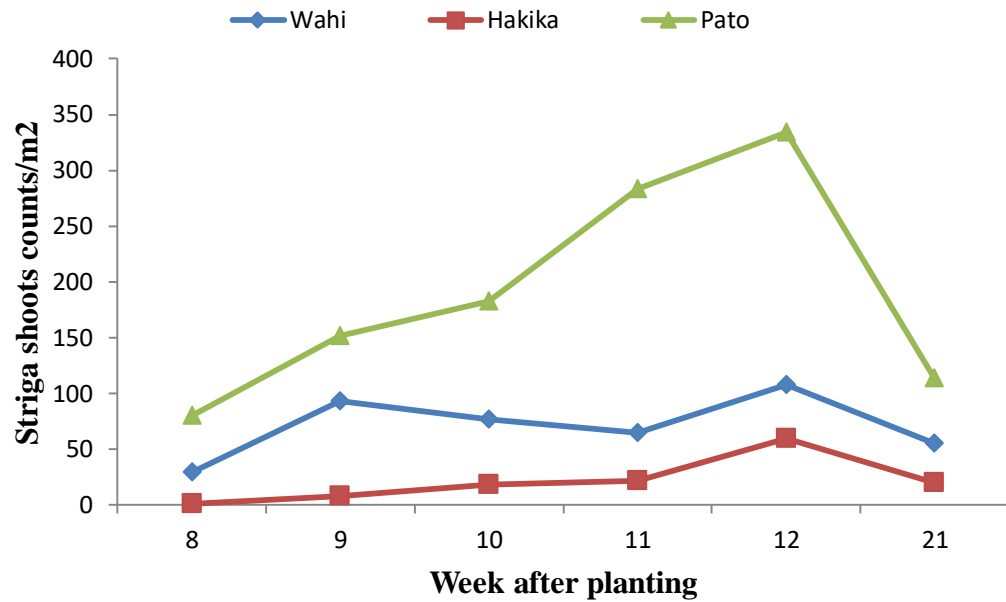
Figure 20: Effect of sorghum genotypes on *Striga* shoots counts/m² at Hombolo.

At Ngamu, at all sampling periods (12 WAP, 15 WAP and 20 WAP), all rates of urea fertilizer did not differ significantly ($P \leq 0.05$) on *Striga* shoots counts/m^2(Fig. 21). At 12 WAP, the lowest number of *Striga* shoots counts/m^2 was recorded with 50 Kg N/ha and the highest number of *Striga* shoots counts/m^2 was recorded with 10 Kg N/ha (Fig. 21). At 15 WAP, the lowest number of *Striga* shoots counts/m^2 was recorded with 50 Kg N/ha and the highest number of *Striga* shoots counts/m^2 was recorded with 20 Kg N/ha (Fig. 21). At harvest (20 WAP), the lowest number of *Striga* shoots counts/m^2 was recorded with 50 Kg N/ha and the highest number of *Striga* shoots counts/m^2 was recorded with 20 Kg N/ha (Fig. 21). Among all sampling periods, the lowest number of *Striga* shoots counts/m^2 was recorded with 50 Kg N/ha (Fig. 21). Sorghum genotypes, Pato and Wahi had significantly highest number of *Striga* shoots counts/ m^2 at all sampling periods than Hakika variety (Fig. 22).
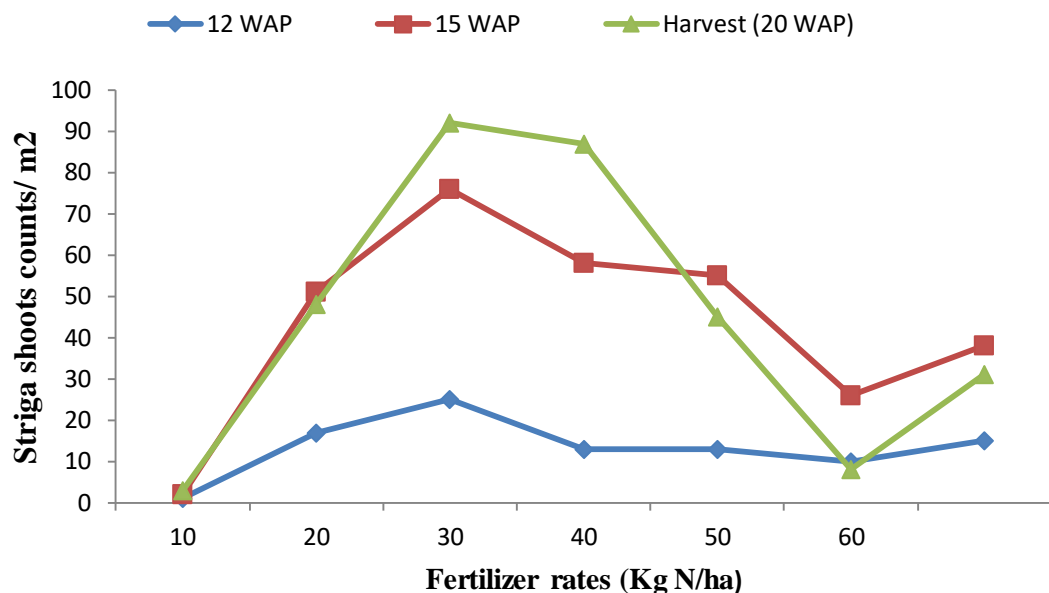
Figure 21: Effect of fertilizer rates on *Striga* shoots counts/m^2 at Ngamu.
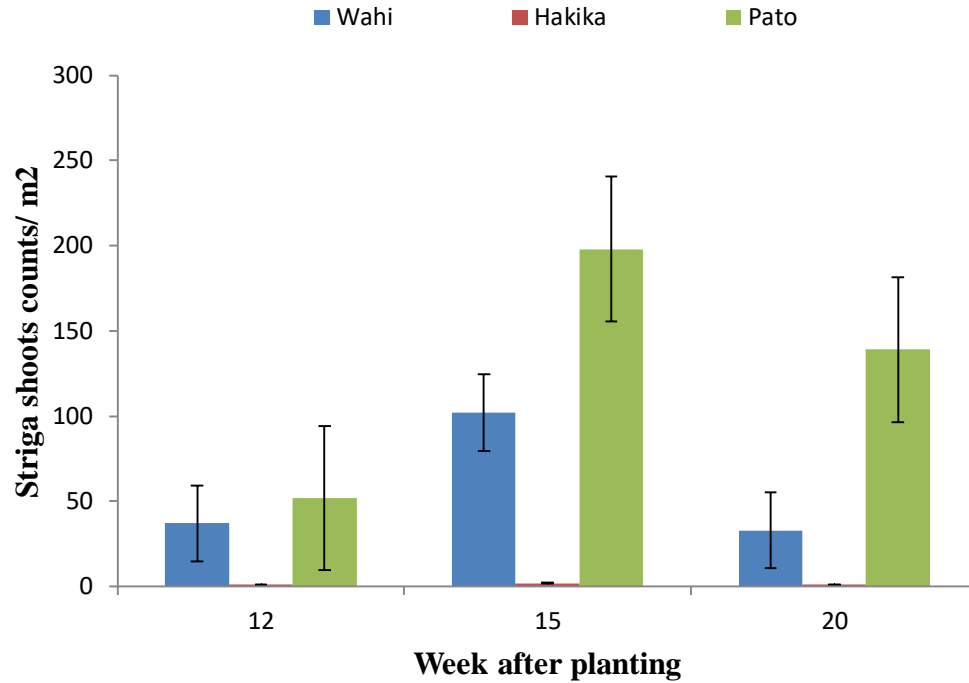
Figure 22: Effect of sorghum genotypes on *Striga* shoots counts/m^2 at Ngamu.

The interaction effect between fertilizer rates and sorghum genotypes varied with sampling periods and locations. At hombolo, there were significant ($P < 0.05$) effects on *Striga* shoot counts/m^2 between fertilizer rates and varieties, except for Hakika variety at 8 WAP, 9 WAP, 10 WAP and 11 WAP (Table 5). At Ngamu, Hakika variety did not have significant ($P < 0.05$) effects on interaction with fertilizer rates on *Striga* shoots counts/m^2 at all sampling periods (Table 6).

Table 5: Interaction of sorghum varieties and nitrogen on *Striga* shoots counts/m² at Hombolo

Sampling period Interactions Varieties * rates (Kg N/ha)	8 WAP	9 WAP	10 WAP	11 WAP	12 WAP	21 WAP
Wahi * 10	0.70a	1.53ab	2.73ab	3.48ab	12.63cdef	5.78abcd
Wahi * 20	1.5abc	2.60ab	4.63abc	6.18abc	16.23ef	7.08abcd
Wahi * 30	1.33abc	2.80abc	3.38ab	4.08ab	12.50cdef	5.40abcd
Wahi * 40	1.00ab	2.40ab	3.38ab	3.73ab	9.83cde	5.25abcd
Wahi * 50	1.15abc	1.45ab	3.05ab	4.68ab	11.3cde	5.10abcd
Wahi * 60	1.13abc	2.50ab	3.33ab	4.40ab	10.80cde	5.48abcd
Hakika * 10	0.70a	0.95a	1.13a	1.13a	5.23abc	1.63b
Hakika * 20	0.83ab	0.95a	1.13a	1.58a	7.75abcd	3.05abc
Hakika * 30	0.70a	0.70a	0.83a	0.83a	1.73a	1.40b
Hakika * 40	0.70a	1.05a	1.05a	0.83a	2.55ab	0.83a
Hakika * 50	0.70a	0.70a	0.07a	0.70a	1.28a	0.70a
Hakika * 60	0.70a	0.70a	0.70a	0.70a	1.65a	0.83a
Pato * 10	2.33c	5.35c	8.65d	11.50d	18.88f	15.15e
Pato * 20	2.13bc	4.08bc	7.60cd	10.08cd	16.45ef	12.78de
Pato * 30	1.85abc	3.28abc	5.95bcd	7.48bcd	12.30cdef	9.70bcde
Pato * 40	1.05abc	1.68ab	3.05ab	4.18ab	10.95cde	5.88abcd
Pato * 50	1.45abc	2.60ab	4.08abc	5.93abc	14.90def	10.18cde
Pato * 60	1.18abc	2.00ab	3.18ab	4.75ab	9.03bcde	6.03abcd
Mean	1.17	2.07	3.26	4.24	9.78	5.68
CV (%)	62.1	77.9	69.5	74.6	47.5	85.4
F-STAT						
Varieties	***	***	***	***	***	***
Fertilizer rates	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns

WAP = weeks after planting, Means followed by different letters are statistically different from each other (p≤0.05) according to Duncan New Multiple Range test.

Key: Significant levels**: ns:** Non significant, **p≤0.1%:** Very highly significant (***)

Table 6: Interaction of sorghum varieties and nitrogen on *Striga* shoots counts/m² at Ngamu

Sampling period Interactions Varieties * rates (Kg N/ha)	12 WAP	15 WAP	20 WAP
Wahi * 10	1.22ab	1.52ab	2.12a
Wahi * 20	1.52ab	2.05ab	3.09ab
Wahi * 30	1.35ab	2.17ab	3.49ab
Wahi * 40	0.93a	1.69ab	2.35ab
Wahi * 50	1.00ab	1.12a	1.42a
Wahi * 60	1.42ab	1.77ab	2.48ab
Hakika * 10	0.71a	0.71a	0.71a
Hakika * 20	0.71a	0.71a	0.71a
Hakika * 30	0.71a	0.71a	0.71a
Hakika * 40	0.84a	0.93a	1.06a
Hakika * 50	0.71a	0.71a	0.71a
Hakika * 60	0.71a	0.71a	0.71a
Pato * 10	1.52ab	2.48ab	2.32ab
Pato * 20	1.92b	3.35b	2.86b
Pato * 30	1.17ab	1.96ab	2.12ab
Pato * 40	1.53ab	2.38ab	2.60ab
Pato * 50	1.44ab	2.22ab	1.97ab
Pato * 60	1.42ab	2.31ab	2.68ab
Mean	1.16	1.64	1.73
CV (%)	48.2	59.8	64.3
F-STAT			
Varieties	***	***	***
Fertilizer rates	ns	ns	ns
Interaction	ns	ns	ns

WAP = weeks after planting, Means followed by different letters are statistically different from each other (p≤0.05) according to Duncan New Multiple Range test.

Key: Significant levels**: ns:** Non significant, **p≤0.1%:** Very highly significant (***)

4.8 *Striga* Shoots Biomass

At Hombolo, urea fertilizer applied at 60 Kg N/ha gave significantly (P ≤ 0.05) lower *Striga* shoots biomass (1.23 g/m²) than the other rates. The highest *Striga* shoots biomass (2.68 g/m²) was recorded from plots treated with 20 Kg N/ha. This was followed by 10 N (2.32 g/ m²), 30 N (1.86 g/ m²), 50 N (1.58 g/ m²) and 40 Kg N/ha (1.43 g/ m²) (Fig. 23). Statistical analysis showed significant (p>0.05) differences in *Striga* shoots biomass for varieties Wahi and Pato when fertilizer was applied (Fig. 23). Variety Hakika had significantly (*P* < 0.05) lower *Striga* shoots biomass (1.02g/m²) than either Wahi (1.61 g/m²) or Pato (2.92 g/m²) (Fig. 23).
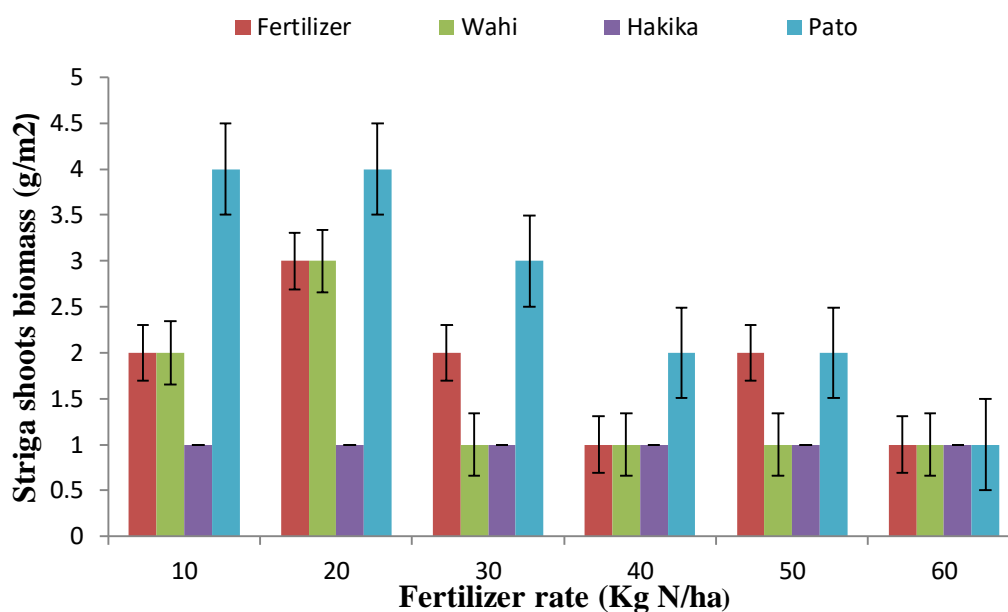
Figure 23: Effect of fertilizer rates on *Striga* shoots biomass in sorghum at Hombolo.

At Ngamu, 50 Kg N/ha significantly (P ≤ 0.05) reduced *Striga* shoots biomass (0.83g/m²) compared with 60 N (0.89 g/ m²), 40 N and 30 Kg N/ha all with a mean of 0.92 g/ m² and 10 Kg N/ha (0.96 g/ m²) (Fig. 24). The highest *Striga* shoots

biomass (1.01g/m^2) was recorded with 20 Kg N/ha (Fig. 24). The results also showed no significant difference (p $\leq$ 0.05) among the rates of nitrogen. Sorghum genotypes, Hakika had significantly ($P \leq 0.05$) lower *Striga* shoot biomass (0.72 g/m^2) than either Wahi (0.91 g/m^2) or Pato (1.04 g/m^2) (Fig. 24).
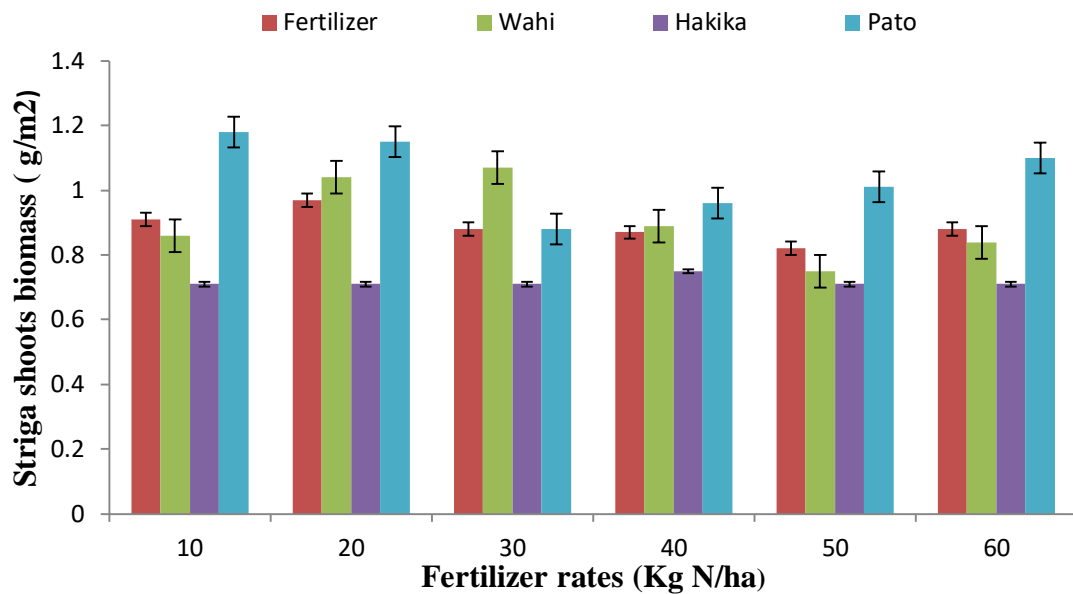
Figure 24: Effect of fertilizer rates on *Striga* shoots biomass in sorghum at Ngamu.

4.9 Economic Returns of Sorghum under Different Rates of N

This sub-section gives a detailed analysis of costs and returns for alternate *Striga* control methods.

4.9.1 Partial budgeting, cost-benefit ratio and marginal analyses

4.9.1.1 Partial budgeting

The partial budget analysis for the alternate *Striga* control methods is presented in Table 7. The results indicate that the costs of fertilizer accounted for a considerable part of the total costs of the six treatments.

At Hombolo, when urea fertilizer was applied, economic analysis showed no maximum net profit was gained as resulted in economic loss (Table 7). The highest loss (Tsh -2 716 500 per hectare) was obtained from the treatment where 30 kg N/ha was applied while the minimum loss (Tsh -1 871 500 per hectare) was obtained from treatment in which 60 kg N/ha was applied (Table 7).

At Ngamu, the analysis revealed that 50 kg N/ha gave a highest net income (Tsh 1 962 160 per hectare) compared with the other treatments. The lowest net income (Tsh 877 160 per hectare) was obtained from the treatment where 10 kg N/ha was applied. Furthermore, all six rates of urea fertilizer were economically viable for *Striga* control methods because they gave positive gross margins.

4.9.1.2 Cost-benefit ratio

At Hombolo, the results showed that for every shilling invested in *Striga* control methods there was a loss for all rates of urea fertilizer (Table 7). Based on the cost-benefit ratio for sorghum production, the results showed that for every shilling invested, there was a loss of -550 Tshs and -810 Tshs for 60 kg N/ha and 30 kg N/ha, respectively.

At Ngamu, Treatments 50 kg N/ha and 20 kg N/ha were more economically attractive because the ratios were higher compared to those of 60, 40, 30 and 10 kg N/ha. Therefore, for every shilling invested there was a return of 470 and 320 Tsh for 50 and 20 kg N/ha, respectively (Table 7).

Table 7: Partial Budgeting Analysis for Alternative *Striga* Control Methods.

Sites	Urea fertilizer rates (kg N/ha)	Yield (t/ha)	Market price (Tsh/kg)	Total production cost (000)	Gross income (000)	Net income (000)	C/B ratio (000)
Hombolo	60	1.52	1000	3391.5	1520	-1871.5	1: -0.55
Hombolo	50	1.27	1000	3371.5	1270	-2101.5	1: -0.62
Hombolo	40	1.3	1000	3376.5	1300	-2076.5	1: -0.61
Hombolo	30	0.64	1000	3356.5	640	-2716.5	1: -0.81
Hombolo	20	1.08	1000	3336.5	1080	-2256.5	1: -0.68
Hombolo	10	1.09	1000	3316.5	1090	-2226.5	1: -0.67
Ngamu	60	5.25	1000	4087.84	5250	1162.16	1: 0.28
Ngamu	50	5.98	1000	4067.84	5980	1912.16	1: 0.47
Ngamu	40	5.2	1000	4072.84	5200	1127.16	1: 0.28
Ngamu	30	5.3	1000	4052.84	5300	1247.16	1: 0.31
Ngamu	20	5.32	1000	4032.84	5320	1287.16	1: 0.32
Ngamu	10	4.89	1000	4012.84	4890	877.16	1: 0.22

B= Benefit and C= Cost

4.9.1.3 Marginal analysis

The marginal analysis for the alternate *Striga* control methods is presented (Table 8). At Hombolo, the marginal analysis indicates that all rates of urea fertilizer gave positive marginal rates of return ranged from 4 730 to 24 140 Tsh per hectare (Table 8).

At Ngamu, the marginal analysis indicates that 40and 10 kg N/ha gavepositive marginal rates of return of 2 330 and 3 800 Tsh per hectare, respectively (Table 8). The correlation between the two sites shows that Ngamu was the best economical attractive location for agriculture investment compared to Hombolo station as had higher cost-benefit ratio and net profit.

Table 8: Marginal Analysis for Alternative *Striga* Control Methods

Sites	Urea fertilizer rates (kg N/ha)	NR_i (000)	NR_o (000)	C_o (000)	C_i (000)	MRR (000)
Hombolo	60	--	-1871.5	3391.5	--	--
Hombolo	50	-2101.5	--	--	3371.5	11.5
Hombolo	40	-2076.5	--	--	3376.5	13.67
Hombolo	30	-2716.5	--	--	3356.5	24.14
Hombolo	20	-2256.5	--	--	3336.5	6.31
Hombolo	10	-2226.5	--	--	3316.5	4.73
Ngamu	60	--	1162.16	4087.84	--	--
Ngamu	50	1912.16	--	--	4067.84	-44.12
Ngamu	40	1127.16	--	--	4072.84	2.33
Ngamu	30	1247.16	--	--	4052.84	-2.43
Ngamu	20	1287.16	--	--	4032.84	-2.27
Ngamu	10	877.16	--	--	4012.84	3.8

MRR= Marginal Rate Return

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil Fertility Status of Experimental Soils

The soil pH values (Table 1) ranged from 6.04 to 6.51. Landon (1991), categorized pH values as follows: > 8.5 = very high, 7.0 – 8.5 = high, 5.5 – 7.0 = medium and < 5.5 = low. In view of this, all soils in the study had medium pH. The pH of most of the soils in the study areas were within the satisfactory range for sorghum production which is 6.0 – 6.8, as reported by Katy *et al*., (2012) and Mariam, (2012).

The organic carbon data for the soils in the areas studied ranged from 0.19 to 0.5% (Table 1). Baize (1993), categorized organic carbon contents as follows: < 0.60% as very low, 0.60 – 1.25% as low and (1.26 – 2.50%) as medium. Based on these categories, soils in these study areas were of very low organic carbon content (Table 1). These levels are similar to those from other studies done by Budotela (1995) in selected grape producing areas of Dodoma region (0.68% OC). Also Letayo (2001) reported very low OC content (0.65%) in millet and groundnut soils of some areas of Dodoma region. Thus, many soils of Dodoma and Singida regions seem to be low in organic carbon. Low soil organic C content on farmers' fields in Dodoma and Singida have been attributed to poor biomass production as a result of limited rainfall as well as burning and removal of crop residues from farmlands for livestock. Similar relashionship of limited rainfall and burning of crop residuals were reported in Savannas of northeastern Nigeria by Kwari and Batey, (1991); Kwari *et al*., (1999).

The values for total N (Table 1) ranged from 0.09 to 0.88%. According to Landon (1991), these values were rated as very low in total N. This means that all the soils analyzed had very low total N contents. Budotela (1995) reported very low N contents in soils of some grape producing areas of Dodoma region (0.06 – 0.08%N). Also Letayo (2001) reported very low N content (0.056%N) in millet and groundnut soils of some areas of Dodoma region. These continue to give evidence that N is a limiting nutrient in many soils of Dodoma and Singida regions. Thus, use of nitrogen fertilizers is necessary for increasing yields in these types of soils on which sorghum is a staple food in most households.

The ranges for extractable Bray-I-P are shown in Table 1. The extractable P ranged from 15.1 to 35.2 mg/kg. Landon (1991) categorized extractable Bray-I-P as; > 50 mg/kg as high, 15 – 50 mg/kg as medium and < 15 mg/kg as low. Based on this classification, soils from study area had medium extractable P contents. Tisdale *et al.,* (1993) reported that P availability is associated with soil pH and in most cases; pH of 6 – 7 is optimum for adequate P availability in soils. Therefore, P should be maintained in those soils in order to increase and sustain sorghum production.

The Cation Exchange Capacity (CEC) ranged from 9 to 18.2 cmol (+)/kg (Table 1). Landon (1991) categorized CEC as follows: 5-12.0 $cmol_c$ (+) kg^{-1} as being low, 12.1-25.0 $cmol_c$ (+) kg^{-1} as medium and 25-40 cmol (+) kg^{-1} as high. Based on these categories, soils in this study ranged from low to medium CEC content. The low CEC levels in the soils may be due to the influence of soil texture and the type of clay minerals and the soil organic matter contents. The medium CEC of the soil is

attributed to the nature of the parent materials from which the soil was developed and the type of the layer silicate clay minerals in the soil. The medium CEC of the soil is an indication of the moderate capacities of the soil to retain nutrients added to the soil in the form of fertilizers.

The values of exchangeable cations in soils from the study areas (Table 1) were as follows;

The values of calcium for soils tested ranged from 2.46 to 5.84 cmol (+)/kg. Landon (1991) categorized levels of exchangeable calcium and indicated that < 2 cmol (+)/kg as very low 2-5 cmol (+)/kg as low, 5-10 cmol (+)/kg as medium, 10-20 cmol (+)/kg as high and > 20 cmol(+)/kg as very high. This implies that soils from the study areas ranged from low to medium. The low calcium content may be due to the low pH values (Chapman, 1973). The medium level of exchangeable Ca in the soil could be attributed to contents of Ca in the parent materials of the soil.

The exchangeable Mg ranged from 0.85 to 2.9 cmol (+)/kg. Landon (1991), reported that soils having < 0.5 cmol (+)/kg as low, 0.5-1.5 cmol (+)/kg as medium, 1.5-3 cmol (+)/kg as high and 3-8 cmol (+)/kg as very high magnesium content. This implies that soils from the study areas ranged from medium to high. The high and medium level of exchangeable Mg in the soils could be attributed by the nature of parent materials.

The values of sodium for the soils tested ranged from 0.14 to 0.28 cmol (+)/kg. Based on the categorization by Landon (1991), > 1 cmol (+)/kg Na^+ contents are in

high range and 0.1-0.3 cmol (+)/kg Na^+ contents are in low range. Thus, all soils in the study are of low range of Na^+. Therefore, based on the observation the soils have no sodicity problem (Landon, 1991). The similar result was reported by Msanya *et al*., (1996) at Kitanda village in Mbiga disctrict.

The values of exchangeable K+ cmol (+)/kg varied from 0.83 to 0.88 cmol (+)/kg. Landon (1991) categorized K content in the soils as follows; 0.1-.0.3 cmol (+) kg^{-1} as low, 0.3 0.7 cmol (+) kg^{-1} as medium, 0.7-2 cmol (+) kg^{-1} as high and > 2 cmol (+) kg^{-1}) as very high. This implies that soils from all locations had high exchangeable K^+. Budotela (1995), reported high exchangeable K^+ in selected grape producing areas of Dodoma district. Most of these areas are also used for sorghum cultivation at times.

Base saturation (Table 1), values ranged 47.6 to 54.4 %. Based on Horneck *et al*., (2011) an acidic soil has a base saturation of about 50 percent, therefore based on this categorization soils from study areas ranged from low to medium. The level of base saturation has been attributed by the nature of the parent rock materials.

5.2 Maximum Emerged *Striga* Shoot Counts

The current study location was the only factor that had significant effect on *Striga* shoots count; showing the geographic and environmental differences. However, maximum number of emerged *Striga* shoots between the two sites varied. The higher *Striga* emergence in plots planted with sorghum at Hombolo over Ngamu could be as a result of difference in cropping patterns, soil nutrients and weather conditions.

5.2.1 Cropping patterns and *Striga* shoots counts

The higher *Striga* emergence in sorghum preceded by sorghum (Continuous sorghum) at Hombolo location over sorghum preceded by maize and groundnuts (intercropping patterns) at Ngamu and the significant differences in *Striga* shoot counts, *Striga* shoots biomass, and sorghum grain yield between both locations and cropping could be as a result of the additional increase in *Striga* seed bank following previous (2014/15) sorghum cropping season. Parker, (1991) reported the similar results and asserted that continuous cropping is generally considered a significant factor in build-up of infestation. Weber *et al*., (1995) went further in the northern savanna of Nigeria and reported that increasing number of *Striga hermonthica* was not surprising in traditional sorghum cropping, as has been linked to increase *Striga hermonthica* seed bank and emerged *S.hermonthica* on maize crops.

Despite from cropping patterns, weather conditions were reported with significant effects on *Striga* shoots counts (Bebawi *et al*., 1984). Mutasova *et al*., (2004) and Sun *et al*., (2007) proved the speculation and reported that the dormancy of *Striga* seeds is known to be associated with moisture and temperature in the soil. Mutasova *et al*., (2004) went further and reported the sensitivity of *Striga* seeds to germination stimulants tendency to increase during pre-conditioning (warm stratification or loss of dormancy) and then decrease again due to the induction of secondary dormancy.

5.2.2 Effect of soil fertility characteristics on *Striga* shoots counts

The soils at both locations were sand clay-textured, with higher sand contents, than clay and silt (Table 1). Indeed it has already been shown in some publications that

soil structure or texture can affect *Striga* seed germinative ability (Kim *et al*., 1997). Poor soil texture and structure can cause an imbalance in nutrients in the soil which may affect *Striga* infestation (Berner *et al*., 1994). Cardwell and Lane (1995) proved this in sandy soil and reported that there was an increase in secretion of strigolactones by the host plants and hence induced more *Striga* germination. Tarfa *et al*., (2001) went further on the results of Cardwell and Lane (1995) and reported that the increase of *Striga* shoots counts in sandy soils is due to poor holding capacity of the mineral nutrients as can be lost more quickly due to leaching. Mean soil pH ranged from 6.04 to 6.54 (Table 1). According to Miriam (2012), the optimum soil pH for *Striga* to thrive best ranges 6.0-6.8 just as for most crops at which nutrients availability is highest.

The total soil N contents in sorghum fields in the two sites were generally low (Table 1). All the fields sampled were in the very low N fertility class (Table 1). Cereals and grain legumes grown in soils with very low N contents can be prone to severe infestation by *Striga* (Lagoke *et al*., 1991; Dugje *et al*., 2006). Nitrogen is thought to inhibit the germination of *Striga* seeds by reducing the production of strigolactones by the host plants; it also increases vegetative growth and makes the host plant more resilient to *Striga* parasitism (Gacheru and Rao, 2001; Miriam, 2012). The mean organic C contents of the fields ranged from 0.19-0.459 % (Table 1). The distribution of soil organic C levels across fields showed that all fields had very low organic C. Vogt *et al*., (1991) demonstrated the importance relationship of soil organic matter and *Striga* infestation. Sherrif *et al*., (1998) and Ayongwa (2011) went further and stated that germination of *Striga* seeds in the soil was reduced due

to increased amount of organic matter. This was due to the fact that organic matter influences the physical and chemical properties of soils that reduce germination of *Striga* seed and their biomass.

Extractable soil P levels did not differ substantially across fields at both locations, with generally higher values at Ngamu (Table 1). Under low soil P levels the exudation of strigolactones by host plants tends to be high, thereby stimulating the germination of *Striga* seeds (Cardoso *et al*., 2010).

The levels of Ca^{2+}, CEC and base saturation were low only at Ngamu and that of Na^+ was low at both locations (Table 1). Under low soil Ca, Na, CEC and base saturation levels the exudation of strigolactones by host plants tends to be high, thereby stimulating the germination of *Striga* seeds. Abdul *et al*., (2012); Miriam, (2012) and Ekeleme *et al*., (2014) reported the similar positive relationship soil Ca, Na, CEC and base saturation to number of capsules/*Striga* plant. Exchangeable K levels were high in both locations (Table 1). The values obtained in all fields across the two sites were above the critical limit and therefore K deficiency may not be expected in crops grown on these soils. Thus, under high exchangeable K levels the exudation of strigolactones by host plants tends to be low, thereby reducing the germination of *Striga* seeds (Miriam, 2012).

In this study total N, organic C, C:N and Na levels were ranged from very low to low in both sites while CEC, Ca and base saturation content in the soil ranged from low to medium (Table 1). Some studies have shown that soil fertility plays a critical role

in *Striga* management (Parker and Riches, 1993; Showemimo *et al*., 2002). Parker and Riches (1993) reported that poor soil fertility encouraged high *Striga* infestation and host damage. For example, in the Sudan savanna ecology of northeastern Nigeria, infestation of *Striga* in cereals was attributed largely to poor soil fertility (Kamara *et al*., 2014). Increase in soil organic matter has been associated with reduction in the germination of *Striga* seeds (Ayongwa, 2011); however, the quality of soil organic matter is also important. Some studies suggest that soils with low C:N ratios tend to have significantly lower *Striga* seed densities than soils with high C:N ratios (Schulz *et al*., 2002; Miriam, 2012). It has been shown that the application of phosphate fertilizers could decrease the exudation of strigolactones by host plant and therefore reduces *Striga* germination and infestation (Cardoso *et al*., 2010).

5.2.3 Effect of temperature and rainfall on *Striga* shoots count

Greater emerged *Striga* shoots at Hombolo than Ngamu was due to the fact that at the former site, weather conditions weremore favorable. Rodenburg *et al*., (2005) noted the importance of weather by showing a large difference in *Striga* emergence in the field between two cropping seasons. High and moderate temperatures increase *Striga* infestation. The optimum temperature for germination and attachment of *Striga* in the soil was reported to be between 30 and 35 ∘C and any deviation could reduce germination (Dawoud and Sauerborn, 1994). The average mean temperature of 30.57 ^{0}C during January- May period at Hombolo favored *Striga* germination and attachment (Fig. 2). In contrast, at Ngamu location the average mean temperature was 28.4 ^{0}C during December-May which could be unfavorable condition for *Striga* germination and attachment (Fig. 2). This observation was also reported by

Hoffmann *et al*., (1997); Aflakpui *et al*., (1998) and stated that reductions in *Striga* infestation due to lower temperatures.

At the onset of an experiment there were differences in rainfall distribution between the two sites. At Ngamu before and after sowing sorghum seeds there were prolonged rainfall throughout the month. Conversely, at Hombolo two days before planting it rains and soon after planting the rainfall tapered for six day then started raining. Similar results on differencein sowing date, rainfall distribution, *Striga* shoots counts and sorghum grain yield were reported by Ekeleme *et al*., (2011).

After thinning and first weeding amount of rainfall or drought between the two sites differed and this can be another reason for the difference in *Striga* infestation. At Ngamu, repeated rains occurred before and after sorghum planting during December– April (820.5mm) (Fig. 1) and this excessive moisture might have reduced *Striga* viability and germination due to seed decay, leaching of germination stimulants and/or onset of dormancy. Similar results were reported by Gbehounou *et al.,* (1996). Oswald and Ransom (2004); Gbehounour *et al*., (2004) proved the results from findings of Gbehounou *et al.,* (1996) and reported effects of long rainy season and erratic rainfall on reducing the number of *Striga* seeds in soil that they germinate and attach. Also, Odhiambo and Ariga (2004) reported low *Striga* infestation during the long rains in Kaura, Kenya and the author went further and started thatcould be attributed to high soil moisture content for an extended period, causing *Striga* seeds to undergo wet dormancy. In contrast, at Hombolo, unreliable and erratic rain started late in December- April (762.7mm) (Fig. 1) and subsequent drought followed which

might have favored *Striga* germination and further infestation. In addition, at Hombolo the length of the period with sufficient rainfall was shorter in a month than at Ngamu. In February it rains for 12 days; in March it rains for 4 days; in April it rains for 9 days and in May it didn't rain even for a single day (Appendix 4). This trend agrees with earlier reports that *Striga* thrives on low rainfall or moisture stress and that continuous wet periods are unfavorable to its development (Ramaiah *et al*., 1983; Shank, 1996). The above mentioned meteorological differences in the two sites and particularly at Hombolo, resulted in more dormant *Striga* seeds at the moment such that sorghum was producing strigolactones and hence more *Striga* infestation in that site.

5.3 Fertilizer Effects on *Striga* Shoot Counts and *Striga* Shoots Biomass

At Hombolo when fertilizer was applied, there was a significant ($P \leq 0.05$) increase in *Striga* shoots counts/m^2 at 10 WAP, 11 WAP and 12 WAP sampling periods (Fig. 19). At Ngamu where fewest *Striga* shoots counts was recorded, the results shows that no significant difference on *Striga* shoots counts/m^2 when fertilizer was applied (Fig. 21).

The highest number of *Striga* shoots counts at Hombolo were recorded at 12 WAP where 10 Kg N/ha was applied. The highest number of *Striga* shoots counts was due to too low nitrogen released from 10 Kg N/ha to inhibit the *Striga* seed germination in the presence of a susceptible hosts (sorghum). The increase in *Striga* shoots counts when fertilizer was applied was also reported by Smaling *et al*., (1991); Kamara *et al*., (2007). The fewest *Striga* shoots count were recorded with 40 Kg N/ha at all

sampling periods, except at 12 WAP (Fig. 19). The reduction of *Striga* shoots counts with the application of 40 Kg N/ha could be due to the higher level of available nitrogen, which reduced production of stimulants.

At both locations, the highest *Striga* biomass was recorded with 20 and 10 Kg N/ha (Fig. 23 and 24). The smallest *Striga* biomass was recorded with 40 and 60 Kg N/ha (Hombolo) (Fig. 23) and 50 Kg N/ha (Ngamu) (Fig. 24). The reduction in *Striga* biomass in plots treated with 40, 50 or 60 Kg N/ha was probably due to the higher quantity of nitrogen supplied by the fertilizer to inhibit the production of stimulants. Ayongwa *et al*., (2006, 2011) reported similar results on the effect of quantity and timing of fertilizer application on *Striga* growth.

At Hombolo, except at 12 WAP, plots treated with 40 Kg N/ha had fewer *Striga* shoots counts than plots with 60 Kg N/ha. At Ngamu, plots applied with 10 N and 50 Kg N/ha had fewer *Striga* shoots counts than plots with 20 N and 60 Kg N/ha, respectively. Despite the high infestation at high nitrogen level (60 Kg N/ha), sorghum plants did not show a loss of vigor. Nitrogen application, therefore, does not reduce *Striga* incidence, but seems to neutralize the harmful effects of *Striga* without reducing the extent of parasitism. Such inconsistencies of high quantity of nitrogen applied and rate of release of nitrogen in controlling *Striga* infestation were also reported by Osman *et al*., (1991); Kranz *et al*., (1998).

The significant interaction between sorghum varieties and nitrogen rates indicate that the susceptible varieties require higher rates of nitrogen to ameliorate the effect of

Striga compared with the resistant varieties. Similar results were reported by Adagba *et al*., (2002) on the incidence of *Striga hermonthica* (del.) benth in upland rice. Also, there were high variations on *Striga* shoots counts/m^2 at both sites, the high variations were due to that, the study was carried in areas that *Striga* infestations were not homogenous (i.e. heterogenous condtions).

5.4 Relationship of *Striga* Shoots Counts, Biomass and Seed Pod Production

Striga numbers and biomass are good indicators of *Striga* seed pod 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 pods. Carsky *et al*., (1994) reported the similar correlation and found that the reduced number of pod forming plants was related to *Striga* above-ground biomass rather than below-ground suppression. The observed close correlation between *Striga* shoots counts and biomass was also reported by Haussmann *et al*., (2001); Kudra *et al*., (2014) and Rodenburg *et al*., (2006) who reported significant correlations between *Striga* biomass and *Striga* seed pod. In the current study, it can be concluded that any fertilizer sources that reduce *Striga* numbers and biomass will cause a proportionate reduction in the *Striga* seed bank.

5.5 Effects of Fertilizer on Sorghum Genotypes under *Striga* Infestation

The effects of nitrogen fertilizer on most growth variables at different growth stages have shown significant effects (P ≤ 0.05) at both locations. Split application of N on sorghum genotypes showed significant effects on days to 50 % flowering, days tophysiological maturity, leaf area index, plant height, plant stand at harvest and

plant biomass. Similar results were reported by Gworgwor (1991). The variations in measurements were obtained with application of different rates of nitrogen fertilizer.

In both locations, the highest plant height (135.8 cm) in Hombolo and in Ngamu (163.37 cm) were obtained with 60 Kg N/ha (Fig. 5 and 6). The highest plant height was due to the higher quantity of nitrogen released with 60 Kg N/ha. The observed correlation between nitrogen and plant height was also reported by Stals and Inze (2001) who showed effect of nitrogen on cell division and cell enlargement which consequently increased plant height.

Days to 50 % flowering and physiological maturity varied with application of fertilizer. At Hombolo, the highest number of days to physiological maturity and 50 % flowering were obtained with application of 30 Kg N/ha and the lowest was obtained with60 Kg N/ha (Fig. 3 and 9) . At Ngamu, the highest number of days to physiological maturity and 50 % flowering were obtained with application of 40 Kg N/ha (Fig. 4 & 10). The lowest number of days to physiological maturity and 50 % flowering were obtained with 50 Kg N/ha. The lowest number of days to physiological maturity and 50 % flowering with 60 and 50 Kg N/ha shows the effectiveness of fertilizer rates to release the efficiency amount of N to accelerate prolonged vegetative growth of the crop. Variation on number of days to physiological maturity and 50 % flowering with fertilizer was also reported by Gworgwor (1991).

Plant stand at harvest and plant shoot biomass on the other hand varied with fertilizer application. In Hombolo, the highest plant stand at harvest was obtained with the application of 20 Kg N/ha while the lowest was with 10 kg N/ha (Fig. 15). The highest plant shoot biomass was recorded in plots treated with 50 kg N/ha and the lowest was with 10 kg N/ha (Fig. 17). At Ngamu, the highest plant stand at harvest were obtained with 60 kg N/ha while the lowest was recorded with 30 Kg N/ha (Fig. 16). The highest plant shoot biomass was recorded in plots treated with 60 kg N/ha and the lowest was from 10 kg N/ha (Fig. 18). The highest plant stand at harvest due to application of 20 kg N/ha (Hombolo) and 60 kg N/ha (Ngamu) indicates the best level of nitrogen to support plant vigorous and cell enlargement while reducing logging effect to the plant species (Gworgwor, 1991) . Also, higher plant shoots biomass with application of 50 kg N/ha (Hombolo) and 60 kg N/ha (Ngamu) indicated the best rates of N that would reduce *Striga* germination and attachment to the host species (Mbwaga *et al.*, 2003 and Ikie *et al.*, 2007).

The response of sorghum genotypes to nitrogen fertilizer rates differed ($P < 0.05$) at Hombolo for leaf area index (Fig. 7). At Ngamu, the leaf area index was not significantly ($P \leq 0.05$) differences when fertilizer was applied. At Hombolo location the highest leaf area index was obtained with the application of 60 kg N/ha and the least was obtained with the application of 10-30 Kg N/ha (Fig. 7). The maximum leaf area index was obtained due to the higher level of N released by the rate to support cell division and enlargement on the plant leaf for higher light interception (Stals and Inze, 2001).

Fertilizer rates showed highly significant (P<0.05) differences between yield variables in Hombolo while in Ngamu significant (P<0.05) differenceswere observed for most attributes except grain yield and grain weight (Table 3). At Hombolo, grain yield of sorghum grown under high *Striga* infestation ranged from 0.64 to 1.52 t/ha and the highest yield (1.52 t/ha) was obtained from sorghum varieties applied with 60 kg N/ha and the lowest from 30 kg N/ha (0.64 t/ha) (Table 3). At Ngamu, where least*Striga* infestation was recorded, urea fertilizer did not show statistical $P \leq 0.05$ different on grain yield (Table 3). Grain yields of sorghum varieties ranged from 4.89 to 5.98 t/ha. The highest grain yield (5.98 t/ha) was obtained from sorghum varieties applied with 50 kg N/ha and the least grain yield (4.89 t/ha) was obtained from sorghum varieties with 10 kg N/ha (Table 3). The highest grain yield obtained from 60 kg N/ha in high infested field (Hombolo) and 50 kg N/ha under least *Striga* infestation (Ngamu) is a major insightof reduced *Striga* germination and attachment.Similar results were reported by Mbwaga *et al*., (2003); Ikie *et al*., (2007); Ibrahim, (2009) and Mrema *et al*., (2017).

In both locations (Hombolo and Ngamu), the highest panicle dry weight 862 g in Hombolo and 3358 g in Ngamu was recorded in plots applied with 60 kg N/ha (Table 3). The least panicle dry weight 406 g in Hombolo and 2623 g in Ngamu was recorded in plots applied with 30 kg N/ha (Table 3). The highest dry panicle weight due to application of nitrogen fertilizer was reported by Ayoub *et al*., (1994).

At Hombolo, there was statistical (P $\leq$ 0.05) difference of seed size among the treatments. Seed size of sorghum varieties ranged from 3.8 to 4.06 g and the highest

seed size (4.06 g) was obtained from sorghum varieties applied with 30 kg N/ha and the lowest from 40 kg N/ha (3.8 g) (Table 3). In Ngamu, the seed size of sorghum varieties ranged from 3.8 to 4.06 t/ha (Table 3). The highest seed size (4.06 g) was obtained from sorghum varieties applied with 30 kg N/ha and the least seed size(3.8 g) was obtained from sorghum varieties treated with 60 kg N/ha (Table 3). The highest seed size obtained for 30 kg N/ha under high and least *Striga* infestation was due to high amount of nitrogen released by the rate to reduce the production of *Striga* stimulants while enhancing cell enlargement to the host plant. Similar results on increasing seed size due to application of nitrogen fertilizer were reported by Yohanna (2014) and Amare (2015).

5.6 Relationship of Days to First *Striga* Emergence, *Striga* Shoot Counts, *Striga* Shoot Biomass and Sorghum Grain Yield

Days to first *Striga* emergency at Hombolo and Ngamu ranged from 57-67and 60-79 days after planting, respectively (Table 4). The results in this study also showed discrepancy of *Striga* shoots biomass, whereas at Hombolo *Striga* shoots biomass recorded ranged from 1.23-2.92 g/m^2 and at Ngamu ranged from 0.72- 1.04 g/m^2. Sorghum grain yields at Hombolo and Ngamu were 0.64 – 1.52 and 2.82- 7.21 t/ha respectively. Delayed *Striga* emergency between the two sites might be due to difference in sowing date, weather conditions and cropping patterns of previous season (2014/15). Late emerged *Striga* shoots can be related with number of *Striga* shoots counts, *Striga* shoots biomass and grain yield of the host crop (i.e. in areas where *Striga* emergence delayed also can lead fewer *Striga* shoots counts during growth period of the host). Similar results on correlation between delaying *Striga*

emergence, attachment, *Striga* shoots counts and *Striga* shoots biomass were reported by Mbwaga *et al*., (2003); Badu-Apraku *et al*., (2006); Abate *et al*., (2014). Conversely, days to first *Striga* emergency might have a link with grain yield of the host crop. This means if the number of *Striga* shoots is associated with time of first *Striga* emergence also can be linked with the grain yield. Similar results on highest grain yield in least *Striga* infested field (late first *Striga* emergence) over higher *Striga* infested field (early *Striga* emergency) were also reported by Badu-Apraku *et al*., (2006); Menkir (2006) and Abate *et al*., (2014). Apart from the supported results of the mentioned findings, in my study I can conclude that differences in sorghum grain yield between Hombolo and Ngamu may be due to the fact that, at Hombolo, the first *Striga* emerged between the stage of blooming and flowering while at Ngamu the first *Striga* emerged between the stage of flowering and soft dough. Therefore based on the number of *Striga* shoots count, *Striga* shoots biomass and days to first *Striga* emergency at the critical period of water and nutrients requirements; grain yields of sorghum at Hombolo must be lower compared to that of Ngamu and this is due to the fact that sorghum performance at Hombolo was severely degraded by *Striga*.

5.7 Effect of Varieties on Growth and Grain Yield Variables of Sorghum Genotypes

Full details of the growth and photosynthesis response of Wahi, Hakika and Pato to nitrogen availability and infection by *Striga asiatica* when grown under field conditions have been presented in different working papers (Mbwaga *et al*., 2003 and Ejeta, 2007). Cultivars differed in susceptibility to *Striga*, using plant shoot

biomass as a sensitive indicator of response, at Ngamu with infested Pato exhibiting the greatest stem biomass (1589.9 g/m^2) and Wahi showing the least depression in stem biomass (358.4 g/m^2) at higher N availability (Fig. 18). Mbwaga *et al*., (2003) presented similar results on increasing stem biomass by Pato than Wahi and Hakika varieties under least *Striga* infestation. At Hombolo, Wahi variety exhibited the greatest stem biomass (759 g/m^2) and the least stem biomass (534 g/m^2) in plots planted with variety Hakika (Fig. 17). Similar results on increasing plant shoots biomass of variety Wahi than Pato under higher *Striga* shoots counts was also reported by Mbwaga *et al*., (2003).

The effect of *Striga* on plant height, leaf area index, plant stand at harvest, days to maturity and days to 50 % flowering was recorded for all varieties. The tallest variety was Pato in both locations. Well-developed leaf for light interception was recorded in plots planted with variety Pato. The increase of plant height and leaf area index in Pato compared to Wahi and Hakika varieties conforms to those of Ejeta *et al*., (1997) and Showemimo *et al*., (2005). At both locations, Pato variety takes longer time to reach physiological maturity and 50 % flowering than the other varieties. The longest time for Pato variety to attained physiological maturity and 50 % flowering was associated withsusceptibility of the variety to *Striga*. As a result, Pato variety failed to maintain its normal growth patterns compared to Wahi and Hakika varieties.The failure of Pato variety to maintain its normal growth patterns was associated with the ability of *Striga* weed on weakens and impairing photosynthesis of the host plant`s. Mbwaga *et al*., (2003) reported similar results of late maturity and 50 % flowering of Pato over Hakika and Wahi varieties.

Sorghum genotypes also showed variability on vigor score and plant damage when evaluated under *Striga* infestation (Table 2). Under high *Striga* infestation (Hombolo) the most vigorous genotypes were Pato and Wahi while the least vigorous was Hakika (Table 2). Pato and Hakika varieties were the most vigorous under low *Striga* infestation (Ngamu) (Table 2). Pato variety had the best plant damage score under both conditions of *Striga* infestations. Similar results were reported by Showemimo *et al*., (2005).

Grain yield of sorghum grown under least *Striga* infestation (Ngamu) ranged from 2.81 to 7.21 t/ha and the highest yield was obtained from sorghum variety Pato and the lowest from Hakika (2.81 t/ha) and Wahi (5.95 t/ha) varieties (Table 3). The same sorghum varieties grown under high *Striga* infestation (Hombolo) produced relatively low grain yields ranging from 0.96 to 1.28 t/ha indicating impact of *Striga* on grain yield (Table 3). The highest grain yield was obtained from sorghum variety Wahi (1.28 t/ha) and the least variety Hakika (0.96 t/ha) (Table 3). The highest grain yield obtained from Wahi variety under highly infested serves as major indicator of *Striga* tolerance (Ejeta, 2007).The highest grain yield in variety Pato in least *Striga* infested field, and highest grain yield in Wahi under high *Striga* infested field was also reported by Mbwaga *et al*., (2003).

5.8 Economic Analysis of the *Striga* Control Technology

The acceptance and suitability of any treatment ultimately depends upon its economic returns and the costs involved.

At Hombolo, when urea fertilizer was applied, economic analysis showed no maximum net profit was gained since it resulted in economic loss. The results showed maximum yield of 1.52 t/ha with 60 kg N/ha but still indicated economic loss (Table 7). On cost-benefit ratio for sorghum production showed that for every shilling invested, there was a loss of -550/= Tshs and -810/= Tshs for 60 kg N/ha and 30 kg N/ha, respectively. Therefore, harvesting a greater yield does not necessary mean gaining more profit, as reported by Mahinda *et al*., (2016). This counterintuitive result may be due to the fact that *Striga* infestation and pressure was so strong at Hombolo that sorghum crop was so severely infested and damaged that it could not support higher sorghum grain yields.

At Ngamu, where farmer's field trial was located, economic analysis showed that the highest net income (Tsh 1 912 160/= per hectare) was obtained from 50 kg N/ha (Table 7) and the lowest income (877 160/= Tsh) was obtained with 10 kg N/ha (Table 7). Based on the benefit-cost ratio for sorghum production, the results showed that for every shilling invested , there was a return of 470 and 220 for 50 kg N/ha and 10 kg N/ha, respectively (Table 7).

Economically, at Hombolo, the best treatments for *Striga* control were 30 and 40 kg N/ha with 24 140 and 13 670 MRR, respectively (Table 8). On the other hand at Ngamu, the best treatments for *Striga* control were 50 and 10 kg N/ha with 2 330 and 3 800 MRR, respectively (Table 8). Similar results have been reported by Jamil *et al*., (2012) and Ibrahim (2009) who showed increases in sorghum grain yield and MRR% with use of fertilizers in a *Striga* infested sorghum fields. Thus, despite the added cost of production at Ngamu, it still had the best economic returns.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The application of 40 kg N/ha at Hombolo was the promising nitrogen fertilizer rates as it reduced *Striga* counts by up to 66 % among sorghum varieties. At Ngamu no statistical (P ≤ 0.05) differences was recorded in *Striga* shoots counts/m^2. Based on the correlation of *Striga* shoots counts, *Striga* biomass, yield response and economic returns, 50 kg N/ha should be the promising fertilizer rates on reducing *Striga* germination and attachment at Ngamu.

Sorghum genotypes also revealedvariability for selection; Hakika and Wahi varieties were the promising resistance/tolerance to *Striga* infestation. Pato supported greater number of *Striga* shoots count and under low*Striga* shoots count/m^2 the genotype yielded higher than the other varieties.

6.2 Recommendations

Based on the empirical findings of the study, the followings are hereby recommended;

1. Because 50 Kg N/ha at Ngamu increased grain yields of sorghum, economically it have potential to be used as a substitute of 60 Kg N/ha in sorghum production in *Striga* infested soils of Singida region. At Hombolo, further economic studies on *Striga* mitigation using high rates of N should be carried out.

2. The study also recommends that, further studies should be carried out in multiple sites in different agro ecological zones. It will be of particular importance to use more than one fertilizer type and sorghum varieties to investigate their genetic yield potential under different rates of nitrogen.

3. Because of least number of *Striga* shoots count/m^2 in plots planted with Hakika and Wahi varieties, suggestion is that they could be promising candidates for immediate deployment of Wahi and Hakika varieties to farmers in *Striga* prone of semi-arid areas of Tanzania.

4. Future breeding efforts should focus onyield traits of Wahi and Hakika varieties as they showedtolerance/or resistance to *S. asiatica.*

REFERENCES

Abate M., Mekbib F., Hussien T., Bayu W and Reda F. (2014). Assessment of genetic diversity in sorghum (*Sorghum bicolor* (L.) Moench) for reactions to *Striga hermonthica* (Del.) Benth. *African Crop Science Journal* 8(8): 1248-1256.

Abbasher, A.A., Hess, D.E. and Sauerborn, J. (1998). Fungal pathogens for biological control of *Striga hermonthica* on sorghum and pearl millet in West Africa. *African Crop Science Journal* 6: 179-188.

Abdul, K., Chemining'wa, G.N and Onwonga, R.N. (2012). Relationships between agronomic practices, soil chemical characteristics and *Striga* reproduction in Dryland areas of Tanzania. *Journal of Agricultural Science Technolology* 2: 1134-1141.

Abunyewa, A.A and Padi, F.K. (2003). Changes in soil fertility and *Striga hermonthica* prevalence associated with legume and cereal cultivation in the Sudan savannah zone of Ghana. *Land Degradation Development* 14: 335–343.

Adagba, M.A., Lagoke, S.T. and Imolehim, E.D. (2002). Nitrogen effect on the incidence of *Striga hermonthica* (Del.) Benth in upland rice. *Acta Agronomica Hungarica* 50 (2): 145-150.

Adugna, A. (2007). The role of introduced sorghum and millets in Ethiopian agriculture. *Semi Arid Tropics enjournal* 3(1): 1-4.

Aflakpui, G.K.S., Gregory, P.J. and Froud-Williams, R. J. (1998). Effect of temperature on seed germination rate of *Striga hermonthica* (Del.) Benth. *Crop Protection* 17: 129–133.

AGRA, (2013). Africa Agriculture status report: Focus on staple crops. In: *Farm risk management for Africa*. (Edited by Braun, *et al*.), 204pp.

Ahmed, S.A., Diffenbaugh, N.S., Hertel, T.W., Lobell, D.B., Ramankutty, N., Rios, A.R. and Rowhani, P. (2011). Climate volatility and poverty vulnerability in Tanzania. *Global Environmental Change* 21(1): 46-55.

Ahonsi, M.O., Berner, D.K., Emechebe, A.M. and Lagoke, S.T. (2004). Effects of ALS inhibitor herbicides, crop sequence, and fertilization on natural soil suppressiveness to *Striga hermonthica*. *Agriculture Ecosystem Environment* 104: 453-463.

Aliyu, L., Lagoke, S.T., Carsky, R.J., Kling, J., Omotayo, O. and Shebayan, J.Y. (2004). Technical and economic evaluation of some *Striga* control packages in maize in the Nigerian Guinea Savanna. *Crop Protection* 23: 65-69.

Alston, J.M., Andersen, M.A., James, J.S. and Pardey, P.G. (2010). Persistence pays: U.S. Agricultural productivity growth and the benefits from public Research and Development spending. New York: Springer. pp. 313-351.

Amare A. (2015). Yield response of local long maturing sorghum varieties to timing of Nitrogen fertilizer application in Eastern Amhara Region, Ethiopia. *Journal of Biology, Agriculture and Health Care* 5(3): 1-7.

ASARECA. (2013). Asareca for celebrating the impacts Annual Report. In: *Striga-*resistant sorghum varieties criss-cross sub region. [www.asareca. org/sites/default/.../D-annual%20report%20-%202013.pdf] Site visited on 22/4/2015.

Assefa, Y., Staggenborg, S. A., and Prasad, V. P. V. (2010). Grain sorghum water requirement and responses to drought stress: Crop Management. [*http:// www.plantmanagementnetworkorg/pub/cm/ reviw/2010*] Site visited on 24/5/2016.

Atera, E. and Itoh, K. (2011). Evaluation of ecologies and severity of *Striga* weed on rice in Sub-Saharan Africa. *Agriculture Biology Journal of modern Africa* 2: 752-760.

Avav, T., Shave, P.A., Magani, E.I. and Ahom, R.I. (2009). Effect of mucuna biomass and N fertilizer on *Striga hermonthica* (Del).Benth infestation in maize (*Zea mays* L.). *Journal of Animal and Plant Science* 4(2): 320-328.

Ayongwa, G.C. (2011). Understanding the diverse roles of soil organic matter in the cereal – *Striga hermonthica* interaction.Dissertation for Award of Degree of Doctor of philosophy (PhD) at Wageningen University, Wageningen, Nerthelands. 131pp

Ayongwa, G.C., Stomph, T.J., Emechebe, A.M. and Kuyper, T.W. (2006). Root nitrogen concentration of sorghum above 2% produces least *Striga hermonthica* seed stimulation. *Annals Applied Biology* 149: 255-262.

Ayoub, M., Quertin, S., Lussier, S. and Smith, D.L. (1994). Timing and levels of nitrogen fertility effects onwheat yield in Eastern Canada. *Crop Science* 34: 748-756.

Babiker, A.G., Ejeta, G. and Mohamed, A. (1996). Chemical control of *Striga hermonthica* on sorghum. In: *Advances in parasitic plant research*. (Edited by Moreno, M.T). Proceedings of the 6th International symposium on parasitic weeds, Cordoba, Spain. pp. 769-773.

Badu-Apraku B., Menkir A., Fakorede M.A.B. (2006) Registration of 16 *Striga* resistant early maturing tropical maize inbred lines. *Crop Science* 46: 1410–1411.

Baize, D. (1993). Soil science analyses: A guide to current use. John Wiley and Sons, Chichester. 208pp.

Barkworth, M. (2003). *Sorghum* Moench. In: Flora of North America Vol 25 Magnoliophyta: Commelinidae: Poaceae, Part 2. Oxford Univ. Press, New York. pp. 626– 630.

Bebawi, F. F., Eplee, R. E. and Norris, R.S. (1985). The dispersion of backpack – applied Ethylene in soil. *Weed Science* 33: 74-77.

Bebawi, F.F., Eplee, R.E., Harris, C.E. and Norris, R.S. (1984). Longevity of witchweed (*Striga asiatica*) seed. *Weed Science* 32: 494– 497.

Berhane, S. (2016). Review on *Striga* management: Scientist Research. *International Journal of Science* 2: 110-120

Berner, D. K., Kling, J. G. and Singh, B. B. (1995). *Striga* Research and Control – A Perspective from Africa. *Plant Disease* 79(7): 652- 660.

Berner, D.K., Cardwell, K.F., Faturoti, B.O., Ikie, F.O. and Williams, O.A. (1994). Relative roles of wind, crop seeds, and cattle in dispersal of *Striga* spp. *Plant Disease* 78(4): 402- 406.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science* 59: 39 - 45.

Bremner, J. M. and Mulvaney, C.S. (1982). Total nitrogen. In: *Methods of soil analysis part 2*, 2nd edn, Monograph no 9. (Edited by Page, A.L, Miller, R.H and Keeney, D. R). American Society of Agronomy, Soil Science Society of America, Madison. 149-158.

Budotela, G. M. R. (1995). Evaluation of Minjingu Phosphate Rock as a source of phosphorus for grapevine production in Dodoma district.Dissertation for Msc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 25-28.

Bueno, A. (1979). Leaf area estimation, growth analysis, and yield evaluation in grain sorghum (*Sorghum bicolor* L. Moench.). Dissertation for Award of Degree of Doctor of philosophy (PhD) at Lowa State University. 7268pp.

California Department of Food and Agriculture. (2006). Witchweed (*Striga asiatica (L.)Kuntze*). Noxious Weed Index. [https://www.cdfa.ca.gov/plant/ipc/encycloweedia/weedinfo/striga.htm] Site visited on 19/5/2015.

Cardoso, C., Ruyter-Spira, C. and Bouwmeester, H. J. (2010). Strigolactones and root infestation by plant-parasitic *Striga*, *Orobanche* and *Phelipanche spp*. *Plant Science* 180: 414- 420.

Cardwell, K.F. and Lane, J.A.(1995). Effect of soils, cropping system and host phenotype on incidence and severity of *Striga gesnerioides* on cowpea in West Africa. *Agriculture Ecosystem and Environment* 53: 253–262.

Carsky, R.J., Singh, L. and Ndikawa, R. (1994). Suppression of *Striga hermonthica* on sorghum using a cowpea intercrop. *Experimental Agriculture Journal* 30: 349 - 358.

Cechin, I. and Press, M.C. (1993). Nitrogen relations of the sorghum *Striga hermonthica* host parasite association – germination, attachment and early growth. *New Phytologist Journal* 124: 681– 687.

Chang'a, L.B., Yanda, P.Z. and. Ngana, J. (2010). Indigenous knowledge in seasonal rainfall prediction in Tanzania: A case of the South-western Highland of Tanzania. *Journal of Geography and Regional Planning* 3(4): 66-72.

Chapman, H.D. (1965). Cation Exchange Capacity. In: *Methods of Soil Analysis* (Edited by Black, C.A.). Agronomy no 9.American Society of Agronomy. Madison, Wisconsin. 891- 901.

Cherif-Ari, O., Housley, T.L. and Ejeta, G. (1990). Sorghum root length density and the potential for avoiding *Striga* parasitism. *Plant and Soil Journal* 121: 67-72.

Ciotola, M., Watson, A.K. and Hallett, S.J. (1996). Impacts of *Fusariumoxysporium*isolate M12-4A upon seed germination of *Strigahermonthica in vitro*. In: *Advances in Parasitic Plant research*. (Edited by Moreno, M.T., Cubero, J.I., Berner, D., Joel, D., Musselman, L.J., and Parker, C.). Proceedings of the 6th International Symposium on Parasitic Weeds, Cordoba, Spain. 871- 878.

Cochrane, V. and Press, M.C. (1997). Geographical distribution and aspects of the ecology of the hemiparasitic angiosperm *Striga asiatica* (L) Kuntze: A herbarium study. *Journal of Tropical Ecology* 13: 371-380.

De Groote, H., Rutto, E., Odhiambo, G., Kanampiu, F., Khan, Z., Coe, R., Vanlauwe, B. (2010). Participatory evaluation of integrated pest and soil fertility management options using ordered categorical data analysis. *Agricultural System Journal* 103(2010): 233– 244.

Dembele, B., Dembele, D., Westwood, J.H. (2005). Herbicide seed treatment for control of purple witchweed (*Striga hermonthica*) in sorghum and millet. *Weed Technology* 19: 629-635.

Doggett, H. (1988). Sorghum 2nd ed. Longman Scientific and Technical, Essex, England, UK. 512pp.

Dugje, I.Y., Kamara, A.Y., Omoigui, L.O. (2006). Infestation of crop fields by *Striga* species in the savanna zones of northeast Nigeria. *Agriculture Ecosystem Environment* 116: 251-254.

East Africa Breweries Limited. (2011). Accelerating value growth in Eastern Africa; Annual report and financial statement. "Value growth encourages communities to craft a vision and set standards for development which respond to the communities' values". 120pp.

East Africa Breweries Limited.(2013). Building East Africa's Most Celebrating Business through Brands, Supply Chain and Reputation. *Financial Report*. 116pp.

ECARSAM. (2014). Sorghum and millet; Increase economic growth and improved livelihoods in ECA while enhancing the quality of the environment. [http://www.asareca.org/press.htm] site visited on 15/8/2015.

Ejeta, G. (2007). Breeding for *Striga* resistance in sorghum: exploitation of intricate host-parasite biology. *Crop Science* 47: 216- 227.

Ejeta, G. and Butler, L.G. (2000a). Parasitic plants. In*: Compandium of Sorghum Diseases, 2nd edition*. (Edited by Frederiksen, R.A. and Odvody, G.N.). *American Phytopathological Society*. 53-56.

Ejeta, G., Babiker, A.G. and Mohamed, A. (1996). Chemical control of *Striga hermonthica* on sorghum. In: *Advances in Parasitic Plant research*. (Edited by Moreno, M. T., Cubero, J.I., Berner, D., Joel, D., Musselman, L.J., and Parker, C.). Proceedings of the 6th International Symposium on Parasitic Weeds, Cordoba, Spain. 769- 773.

Ejeta, G., Butler, L.G., Hess, D.E., Obilana, T. and Reddy B.V. (1997). Breeding for *Striga* resistance in sorghum. In: *proceedings of the International Conference on Genetic Improvement of sorghum and pearl* millet.Sep. 22 - 27 1996, Texas, USA. 504-516.

Ejeta, G., Mohammed, A., Rich, P., Melakeberhana, A., Housley, T.L. and Hess D.E. (2000b). Selection for mechanisms of resistance to *Striga* in sorghum. In: *Breeding for Striga resistance in cereals*. (Edited by Haussmann, B.I.G *et al*.), Proceedings of a workshop held at IITA, Ibadan, Nigeria. Margraf Verlag, Weilker Sheim, Germany. pp. 29- 37.

Ekeleme F., Jibrin J. M., Kamara A.Y., Oluoch M., Samndi A.M and Fagge A. A. (2014). Assessment of the relationship between soil properties, *Striga hermonthica* infestation and the on-farm yields of maize in the dry Savannas of Nigeria. *Crop Protection* 66: 90-97.

Ekeleme F., Kamara A.Y., Omoigui L.O., Chikoye D, Dugje I.Y and Tegbaru A. (2011).Effect of sowing date on *Striga* infestation and yield of sorghum (*Sorghum bicolor* [L.] Moench) cultivars in the Sudan savanna of northeast Nigeria. *African Journal of Agricultural Research* 6(14): 3240-3246.

FACTFISH. (2014). Research made simple. [http://www.factfish.com/statisticcountry/tanzania/sorghum,%20production%20quantity] Site visited on 17/8/2015.

FAO and ICRISAT. (1996). The world sorghum and millet economies: Facts, trends and outlook. FAO, Rome, Italy. 67pp.

FAO. (2004). Food and Agriculture Organisation of United Nations, 2004. FAOSTAT. [http://www.fao.org/docrep/018/i3107e/i3107e.pdf] Site visited on 19/5/2015.

FAO. (2012). Database of agricultural production.FAO Statistical Databases (FAOSTAT). [http://faostat.fao.org/default.aspx]. Site visited on 22/4/2015.

FAOSTAT. (2011). Database of agricultural production.FAO Statistical Databases (FAOSTAT). [http://faostat.fao.org/default.asp*x*] Site visited on 24/4/2015.

FAOSTAT. (2013). Food and Agricultural Organization of the United Nations Statistics. [http:// faostat3.fao.org] Site visited on 18/5/2015.

FAOSTAT. (2014). Production_crops_sorghum._Tanzania. [http:// faostat.fao.org/ site/567/DesktopDefault.aspx?PageID=567#ancor] Site visited on 15/5/2015.

Fen, D. B., Steven, G. H., Venne, J. and Watson, A.K. (2007). Biocontrol using *Fusarium oxysporum*; a critical component of integrated *Striga* management. In: *Integrating New Technologies for Striga Control*: *Towards Ending the Witch-hunt*. (Edited by Ejeta, G. and Gressel, J.). World Scientific Publishing Company, Singapore. 283- 300.

Franke, A. C., Ellis-Jones J., Tarawali, G., Schulz, S., Hussaini, M. A., Kureh, I., White, R., Chikoye, D., Douthwaite, B., Oyewole, B. D and Olanrewaju, A. S. (2006). Evaluating and scaling-up integrated *Striga hermonthica* control technologies among farmers in northern Nigeria. *Crop Protection* 25: 868-878.

Gacheru E. and Rao, M. R. (2001). Managing *Striga* infestation on maize using organic and inorganic nutrient sources in Western Kenya. *International Journal of Pest Management*. 47: 233-239.

Gbèhounou G., Adango E., Hinvi J. C and Nonfon R. (2004). Sowing date or transplanting as components for integrated *Striga hermonthica* control in grain-cereal crops. *Crop Protection* 23: 379- 386.

Gbehounou, G., Pieterse, A. H. and Verkleij, J. A. C. (1996). The decrease in seed germination of *Striga hermonthica* in Benin in the course of the rainy season is due to a dying-off process. *Experientia* 52: 264–267.

Gee, G.W. and Bauder, J.W. (1986). Particle size analysis. In: *Methods of soil analysis part 1, 2nd edn,* Monograph no 9. (Edited by Page, A.L, Miller, R.H and Keeney, D.R). American Society of Agronomy, Soil Science Society of America, Madison. pp. 383- 409.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedure for agricultural research. 2nd edition, John Wiley and Sons Co, New York. 680pp.

Gurney, A. L., Slate, J., Press, M. C. and Scholes, J. D. (2006). A novel form of resistance in rice to the angiosperm parasite *Striga hermonthica*. *New phytologist* 169: 199-208.

Gurney, A.L., Taylor, A., Mbwaga, A., Scholes, J.D. and Press M.C. (2002). Do maize cultivars demonstrate tolerance to the parasitic weed *Striga asiatica*. *Weed Research* 42: 299-306.

Gworgwor, N. A., Hudu, A. I. and Joshua, S. D. (2002). Seed treatment of sorghum varieties with brine (NaCl) solution for control of *Striga hermonthica* in sorghum. *Crop Protection* 21: 1015-1021.

Gworgwor, N.A., and Weber, H.C. (1991).Effect of N application on sorghum growth, *Striga* infestation and osmotic pressure of the parasite in relation to the host. *Journal of Plant Physiology*. 139: 194-198.

Harlan, J. R. and Dewet, J. M. J. (1972). A simplified classification of cultivated sorghum. *Crop Science* 12: 172-176.

Haussman, B.I.G., Hess, D.E., Omanya, G.O., Folkertsma, RT., Reddy, B.V.S., Kayentao, M., Welz, H.G. and Geiger, H.H. (2004). Genomic regions influencing resistance to the parasitic weed *Striga hermonthica* in two recombinant inbred populations of sorghum. *Theorical Applied Genetics* 109: 1005-1016.

Haussmann, B.I.G., Hess, D. E., Reddy, B. V., Welz, H.G. and Geiger, H.H. (2000a). Analysis of resistance to *Striga hermonthica* in diallel crosses of sorghum. *Euphytica* 116: 33-40.

Haussmann, B.I.G., Hess, D.E. and Reddy, B.V.S. (2001). Quantitative-genetic parameters of sorghum growth under *Striga* infestation in Mali and Kenya. *Plant Breeding* 120: 49 -56.

Haussmann, B.I.G., Hess, D.E., Welz, H.G. and Geiger, H. H. (2000b). Improved methodologies for breeding *Striga*-resistant sorghums. *Field Crops Research* 66: 195-211.

Hearner, S. J. (2009). Control- the *Striga* conundrum. *Pest Management Science* 65: 603-614.

Hoffmann G., Diarra L., Ba I and Dembele, D. (1997). Parasitic plant species of food crops of Africa: Biology and impact study in Mali. *Agriculture Development* 13: 30-51.

Horneck, D. A., Sullivan, D. M., Owen, J. S. and Hart, J.M. (2011). Soil Test Interpretation Guide. Oregon State University, EC 1478-E. 1-12. [http://extension.oregonstate.edu/catalog/] Site visted on 16/06/2016.

Ibrahim, H. (2009). Economics of control methods for witch weed, *Striga hermonthica* in the Northern Guinea Savanna of Nigeria. Dissertation for Award of Degree of Doctor of Philosophy (PhD) at the University of Ilorin, Ilorin, Nigeria. 127pp.

IITA. (1997). *Striga* Research Methods— A manual. In: *IITA Striga Research Group for the Pan African Striga Control Network*. (Edited by Berner D. K *et al*.), Ibadan, Nigeria. Pan-African *Striga* Control Network 2: 4- 6.

Ikie, F.O., Schulz, S., Ogunyemi, S., Emechebe, A.M. and Togun, A.O. (2007) Influence of legume cropping patterns and organic/inorganic soil amendments on *Striga*seed bank and subsequent sorghum performance. *Advances in Environmental Biology* 1: 11-19.

Ikie, F.O., Schulz, S., Ogunyemi, S., Emechebe, A.M., Togun, A.O. and Dana K. B. (2006). Effect of Soil Fertility on soil chemical properties and sorghum performance under *Striga* infestation. *World journal of Agricultural Sciences* 2 (4): 367-371.

Invasive.org. (2006). *Striga asiatica* witchweed. The Bugwood Network, USDA Forest Service and USDA APHIS PPQ. [https://www. Invasive speciesinfo.gov/plants/witchweed.shtml] Site visited on 19/02/2015.

Jamil, M., Charnikhova, T., Cardoso, C., Jamil, T., Ueno, K., Verstappen, F., Asami, T. and Bouwmeester, H. J. (2011). Quantification of the relationship between strigolactones and *Striga hermonthica* infection in rice under varying levels of nitrogen and phosphorus. *Weed Research* 51: 373- 385.

Jamil, M., Kanampiu, F.K., Karaya, H., Charnikhova, T and Bouwmeester, H. J. (2012). *Striga hermonthica* parasitism in maize in response to N and P fertilizers. *Field Crops Research* 134: 1-10.

Joel, D.M. (2000). The long-term approach to parasitic weeds control: manipulation of specific developmental mechanisms of the parasite. *Crop Protection* 19: 753-758.

Johnson, D.E., Riches, C.R., Diallo, R. and Jones, M. J. (1997). *Striga* on rice in West Africa: crop host range and the potential of host resistance. *Crop Protection* 16: 153-157.

Kamara, A.Y., Ekeleme, F., Jibrin, M.J., Tarawali, G., Tofa, I. (2014). Assessment of level, extent and factors influencing *Striga* infestation of cereals and cowpea in Sudan savanna ecology of northern Nigeria. *Agriculture Ecosystem Environment* 188: 111-121.

Kamara, A.Y., Menkir, A., Chikoye, D., Omoigui, L.O. and Ekeleme, F. (2007). Cultivar and nitrogen fertilization effects on *Striga* infestation and grain yield of early maturing tropical maize. *Maydica* 52: 415 - 423.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K. and Gressel, J. (2003). Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls *Striga*spp. and increases yields in several African countries. Crop *Protection* 22: 697-706.

Kanampiu, F.K., Ransoma, J.K. and Gressel, J. (2001). Imazapyr seed dressings for *Striga*control on acetolactate synthase target-site resistant maize. *Crop Protection* 20: 885- 895.

Kanyeka, E., Kamala, R. and Kasuga, R. (2007). Improved agricultural technologies recommended in Tanzania 1st Edition. Department of Research and Training, Ministry of Agriculture Food Security and Co-operatives. Dar es salaam, Tanzania. 14-19.

Katy, B., Daryl, B.A., Apurba, S., Chad, G.S., Hailin, Z. and Chad, P. (2012). Determining critical soil pH for grain sorghum production. *International Journal of Agronomy*. 1- 6.

Kelly, N., Darren, J., Kriticos, J.K.S., Tania, Y. and Noboru, O. (2014). *Striga asiatica* (Witchweed). Harvest Choice Pest Geography. St. Paul, MN: InSTePP-HarvestChoice. pp. 1-6.

Kilasara, M., Boa, M.E., Swai, E.Y., Sibuga, K.P., Boni, H. M. J. and Kisetu, E. (2015).Effect of in situ soil water harvesting techniques and local plant nutrient sources on grain yield of drought- resistant sorghum varieties in Semi-arid Zone, Tanzania. In: *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa*. Rattan Lal, Bal Ram Singh, Dismas L. Mwaseba. David Kraybill, David O. Hansen, Lars Olay Eik (eds), Springer International Publishing Switzerland. 255- 271.

Kim, S.K., Lagoke, S.T.O and The, C. (1997). Observations on field infection by witch-weed (*Striga species*) on maize in West and Central Africa. *International Journal of Pest Management* 43: 113–121.

Kimber, C.T.,(2000). Classification, origin of domesticated sorghum, and its early diffusion to India and China. In: *Sorghum: Origin, History, Technology and Production*. (Edited by Smith, W. C. and Frederiksen, R. A). Wiley and Sons, New York. 98pp.

Kiruki, S., Onek, L.A. and Limo, M. (2006). Azide based mutagenesis suppresses *Striga hermonthica* seed germination and parasitism on maize varieties. *African Journal of Biotechnology* 5: 866- 870.

Kramer, P. J. (1983). Water Relation of Plants. Academic Press, London, UK. 482pp.

Kranz, B., Fugger, W.D., Kroschel, J. and Sauerborn, J. (1998). The influence of organic manure on *Striga hermonthica* (Del.) Benth.infestation in Northern Ghana. In: *Towards sustainable land use: furthering cooperation between people and institutions*. (Edited by Blume, H. P., Egger, H., Fleischhauer, E., Hebel, A., Reij, C. and Steiner, K.G). *Advanced Geological Ecology* 31(1): 615 -619.

Kraybill, D. and Michael, K. (2009). Analysis of relative profitability of key Ugandan agricultural enterprises by agricultural production zone. Uganda Strategy Support Program (USSP) brief no 7. International Food Policy Research Institute, Washington DC. 1-4pp.

Kuboja, N.M. and Temu, A.E. (2013). Comparative economic analysis of tobacco and groundnut faming in Urambo district, Tabora, Tanzania. *Journal of Economics and Sustainable Development* 4(19): 104-111.

Kudra, A., Chemining'wa, G. N. and Sibuga, K. P. (2014).*Strigaasiatica*growth and seed production in response to organic and inorganic P – fertilizers. *International Journal of Agricultural Science* 2(1): 6-12.

Kudra, A., Chemining'wa, G.N. and Onwonga, R.N. (2012).Relationships between agronomic practices, soil chemical characteristics and *Striga*reproduction in dryland areas of Tanzania. *Journal of Agricultural Science and Technology*. 1- 8.

Kujit, J. (1969). The biology of parasitic flowering plants. University of California Press, Berkeley, USA. 368pp.

Kwari, J. D and Batey, T. (1991). Effect of heating on phosphorus sorption and availability in some northeast Nigerian soils. *Journal of Soil Science* 42: 381- 388.

Kwari, J.D., Nwaka, G.I.C., Mordi, R.I. (1999). Studies on selected soil fertility parameters in soils of northeastern Nigeria. I. Phosphate sorption. *Journal of Arid Agriculture* 9: 61-70.

Lagoke, S.T.O., Parkinson, V., Agunbiade, R.M. (1991). Parasitic weeds and control methods in Africa. In: Proceedings of combating *Striga* in Africa. (Edited by Kim, S.K.), IITA, Ibadan, Nigeria. 3 - 14.

Landon, J.R. (1991). Booker Tropical Soil Manual.*A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Longman Scientific and Technical Publishers. Essex. 474pp.

Leliveld, A., Dietz,T., Klaver,W., Kilama, B. and Foeken,D. (2013). Agricultural dynamics and food security trends in Tanzania Research Report. In: *Developmental Regimes in Africa (DRA) Project ASC-AFCA Collaborative Research Group: Agro-Food Clusters in Africa (AFCA)*. Akinyoade, A., Heleen, S., Sebastiaan, S and Merel, V. W (eds). 48pp.

Letayo, E. A. (2001). Effect of tillage practices and spatial arrangement on pearl millet and groungnuts intercropping in Dodoma. Dissertation for Award of Msc Degree at Sokoine University of Agriculture, Morogoro. Tanzania. 22-23.

Letayo, E.A., Saadan, H.M., Mndolwa, S.L., Gupta, S.C. and Monyo, E.S. (1996). Evaluation of the performances and farmers preferences for pearl millet varieties in Tanzania. In: *Drought –tolerant crops of Southern Africa: Proceedings of the SADC/ICRISAT Regional Sorghum and Pearl Millet Workshop*. (Leuschner, K., and Mathe, C.S. eds), 25-29 July 1994, Gaborone, Botswana, Patacheru 502 324, Andhra Pradesh India. International Crops Research Institute for the Semi-Arid Tropics. 65-70.

Mac opiyo, l., vitale, J. and sanders, J. (2009). Ex-ante assessment of *Striga* control in East Africa.kilimo trust. 119pp. [http://www.parasite-project.org/.../ Kilimo-trust-2009-Ex-Ante_Impact] Site visited on 30/5/2015.

Mahinda, A.J. (2014). Effect of drip irrigation on the production and economic returns of Sorghum (*Sorghum bicolor*) in semi-arid areas of Tanzania. Dissertation for Award of MSc Degree at University of Nairobi, Nairobi, Kenya. 77pp.

Mahinda, A.J., Gachene, C.K.K. and Kilasara, M. (2016).Economic impact of drip irrigation regimes on sorghum production in semi-arid areas of Tanzania. In: *Climate change and multi-Dimensional Sustainability in African Agriculture*. Rattan Lal, Bal Ram Singh, Dismas L. Mwaseba. David Kraybill, David O. Hansen, Mosogoya T and Lars Olay Eik (eds), Springer International Publishing Switzerland. 227- 235.

Matusova, R., van Mourik, T and Bouwmeester, H. J.(2004). Changes in the sensitivity of parasitic weed seeds to germination stimulants. *Seed Science Research* 14: 335–344.

Mbwaga, A. M. and Riches, C. R. (2003). Integrated management of *Striga* species on cereal crops in Tanzania: Final Technical Report, Crop Protection Programmes R7564 (ZA 0369). 72pp.

Mbwaga, A.M. and Obilana, A.T. (1993). Distribution and host specificity of *Strigaasiatica* and *S.hermonthica* on cereals in Tanzania: a preliminary study. *International Journal of Pest Management* 39: 449-451.

Mbwaga, A.M., Riches, C. R. and Ejeta, G. (2007).Integrated *Striga* management to meet Sorghum market demands in Tanzania. In Ejete G, Gressel J. (eds). *Integrated New Technologies for Striga Control Towards Ending the Witch- hunt*. World Scientific Publishing Co Pte.Ltd. 253-64.

Mbwika, J.M., Odame, H. and Ngungi, E.K. (2011). Feasibility study on *Striga* control in sorghum. Nairobi, African Agricultural Technology Foundation. Majestic printing works, Nairobi, Kenya. 78pp.

McLean, E.O. (1986). Soil pH and lime requirement. In: *Methods of Soil Analysis, part 2, Chemical and Mineralogical Properties, 2ⁿᵈ Edition.* (Edited by Page, A. L., Miller, R. H. and Keeny, D. R). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin. *Agronomy Monograph 9*: 199-223.

Menkir, A. (2006). Assessment of reactions of diverse maize inbred lines to *Striga hermonthica* (Del.) Benth. *Plant Breeding* 125: 131- 139.

Miriam, L. (2012). Soil fertility status and *Striga hermonthica* infestation relationship due to management practices in Western Kenya. Dissertation for Award of MSc Degree at Swedish University of Agricultural Sciences. 96pp.

Mitaru, B.N., Mgonja, M.A., Rwomushana, I. and Opio, F. (eds). (2012). Integrated sorghum and millet sector for increased economic growth and improved livelihoods in Eastern and Central Africa. In: *Proceedings of the ECARSAM Stakeholders Conference*. 20–22 November 2006, Dar es Salaam, Tanzania. [http://www.asareca.org/../Integrated% 20sorghum%20 and%20millet%20] Site visited on 26/5/2015.

Mohamed, A., Ellicott, A., Housley, T.L. and Ejeta, G. (2003). Hypersensitive response to *Striga* infection in sorghum. *Crop Science* 43: 1320-1324.

Mohamed, K.I., Musselman, L.J. and Riches, C.R. (2001). The genus *Striga scrophulariaceae* in Africa. *Annals of the Missouri Botanical Garden* 88: 60-103.

Mohamed, K.I., Papes, M., Williams, R., Benz, B.W. and Peterson, A.T. (2006). Global invasive potential of 10 parasitic witch-weeds and related *Orobanchaceae*.*Ambio* 35: 281 - 288.

Monyo, E.S., Ngereza, J, Mgonja, M.A., Rohrbach, D.D., Saadan, H.M. and Ngowi P. (2004). Adoption of improved sorghum and pearl millet technologies in Tanzania. *International Crops Research Institute for the Semi-Arid Tropics*. 28pp.

Mrema E., Shimelis H., Laing M and Bucheyeki T. (2017) Farmers' perceptions of sorghum production constraints and Striga control practices in semi-arid areas of Tanzania. *International Journal of Pest Management* 63(2): 146-156.

Msanya, B.M., Wickama, J.M., Kimaro, D.N., Magogo, J.P. and Meliyo, J.L. (1996). Investigation of the environmental attributes for agricultural development in Kitanda village, Mbinga district, Tanzania.Technical report 5. Miombo Woodland Research Project, Natural Resource Study Team. Department of Soil Science, Sokoine University of Agriculture, Morogoro, and Ministry of Agriculture National Soil Service, Tanga, Tanzania. 38pp.

Ndung'u, D.K. (2009). Mutagenesis and development of herbicide resistance in sorghum for protection against *Striga*. Dissertation for Award of Degree of Doctor of philosophy (PhD) at University of Kwazulu Natal, South Africa. 183pp.

Nelson, D.W. and Sommers, L.E. (1982).Total organic carbon. In: *Methods of Soil Analysis, Part 2*. Chemical and Microbiological Properties. American Society of Agronomy, Madison. 539-579.

Obilana, A.B., Presada-Rao, K.E., Mangombe, N. and House, L.R. (1996). Classification of Sorghum races in the southern Africa Sorghum germplasm. In: *Drought –tolerant crops for Southern Africa. Proceedings for the SADC/ICRISAT Regional Sorghum and Pearl Millet Workshop*. (Leuschner, K., and Manthe, C.S., (eds.), 25-29 July 1994, Gaborone, Botswana Patacheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 113-118pp.

Odhiambo G.D and Ariga E.S. (2004). Effect of intercropping maize and beans on *Striga* incidence and grain yield. In: *Proceedings of the 7th Eastern and Southern African Regional Maize Conference*. (Edited by Friesen *et al*.), 11th – 15th February, 2001, Nairobi, Kenya. CIMMYT (International Maize and Wheat Improvement Center). 183-186pp.

Oehl, F., Oberson, A., Tagmann, H.U., Besson, J.N., Dubois, D., Mader, P., Roth, H.R. and Frossard, E. (2001). Phosphorus budget and phosphorus availability in soils under organic and conventional farming. *Nutrient Cycling in Agroecosystems* 62: 25-35.

Osman M.A., Raju P.S and Peacock J.M. (1991). The effect of soil temperature, moisture and nitrogen on *Striga asiatica* (L.)Kuntze seed germination, viability and emergence on sorghum (*Sorghum bicolor* L. Moench) roots under field conditions. Springer Internation publishing 131(2): 265- 273.

Oswald, A. and Ransom, J. K. (2001). *Striga* control and improved farm productivity using crop rotation. *Crop Protection* 20: 113- 120.

Oswald, A. and Ransom, J. K. (2004). Response of maize varieties to *Striga* infestation. *Crop Protection* 23: 89– 94.

Oswald, A., Ransom, J.K., Kroschel, J. and Saurborn, J. (2001). Transplanting maize (*Zea mays*) and sorghum (*Sorghum bicolour*) reduces *Striga hermonthica* damage. *Weed Science* 49: 346- 353.

Parker, C. (1984). The influence of *Striga* species on sorghum under varying nitrogen fertilization. In: *Proceedings of the third international symposium on parasitic weeds*. (Edited by Parker, C. *et al.*), Aleppo, Syria: 90-98.

Parker, C. (1991). Protection of crops against parasitic weeds. *Crop Protection* 10: 6- 22.

Parker, C. and Riches, C.R. (1993). Parasitic weeds of the worlds: Biology and control. CAB International, Wallingford, UK. 332pp.

Patil, V.L. (2007). Effect of farmyard manure, nitrogen and trap crops on *striga* incidence, growth and yield of *kharif* sorghum (*Sorghum bicolor* (L.) moench.). Dissertation for Award of MSc Degree at Dharwad University of Agricultural Sciences. 92pp.

Perrin, R., Anderson, J., Winkelmann, D. and Moscardi, E. (1988) *From Agronomic Data to Farmer Recommendations: An Economic Training Manual.* CIMMYT: Mexico. [http://www.cimmyt.org]. Site visited on 23/10/2015.

Ramaiah, K.V., Parker, C., Vasudeva Rao, M.J. and Musselman, L.J. (1983). *Striga* identification and control handbook. Information Bulletin No. 15. Patancheru, A. P., India: International Crops Research Institute for the Semi-Arid Tropics. 45pp.

Ransom, J.K. (2000). Long term approaches for the control of *Striga* on cereals: field management options. *Crop Protection* 19: 759-763.

Rao, M.J. and Musselman, L.J. (1987). Host specificity in *Striga* species and physiological "strains". In: *Parasitic Weeds in Agriculture*. (Edited by Musselman, L. J.), Boca Raton, Florida, USA. 12- 16.

Rebeka, G.T. (2013). Integrating Sorghum [*Sorghum bicolor* (L.)Moench] Breeding and Biological Control Using *Fusarium oxysporum* against *Striga hermonthica* in Ethiopia. Dissertation for Award for Degree of philosophy (PhD) at University of KwaZulu-Natal, South Africa. *crop science* 53: 183pp.

Reda, F. and Verkleij, J.A. (2007). Cultural and cropping systems approach for *Striga* management a low cost alternative option in subsistence farming. In: *Integrating New Technologies for StrigaControl: Towards Ending the Witch-hunt*. (Edited by Ejeta, G. and Gressel, J.), World Scientific Publishing Co., Singapore. 229-240.

Rich, P.J., Grenier, C. and Ejeta, G. (2004). *Striga* resistance in the wild relatives of sorghum. *Crop Science* 44: 2221- 2229.

Riches, C.R. (1998). *Striga* in Uganda: A survey of the literature and opportunities for collaborative research. Review undertaken for the DFID Crop Proptection Programme. Natural Resources Institute, Chatham Maritime, Kent. 14pp.

Riches, C.R. (2003). Integrated Management of *Striga* species on cereals crops in Tanzania. Final Techinical Report, R7564 (ZA0369). Natural Resources Institute, Chatham, Kent. 72pp.

Riopel, J. L. and Timko, M. P. (1995). Haustorial initiation and differentiation. In: *Parasitic Plants*. (Edited by Press, M. C. and Graves, J. D.), Chapman and Hall, London. 39- 79.

Rodenburg, J. (2005). The role of sorghum genotype in the interaction with the parasitic weed *Striga hermonthica*. Dissertation for Award of Degree of Doctor of philosophy (PhD) at Wageningen University, Wageningen, Netherlands. 152pp.

Rodenburg, J., Bastiaans, L., Kropff, M.J. and Van Ast, A. (2006). Effects of host plant genotype and seedbank density on *Striga* reproduction. *Weed Research 46*: 251- 263.

Rohrbach, D.D. and Kirimwaggulu, J. A. B. (2007). Commercialization prospect for sorghum and pearl millet in Tanzania. *An open access Journal* 3: 3- 9.

Saini, H. S. (1997). Effects of water stress on male gametophyte development in plants. *Sex Plant Reproduction* 10: 67- 73.

Schulz, S., Hussaini, M. A., Kling, J. G., Berner, D. K. and Ikie F. O. (2002). Evaluation of Integrated *Striga hermonthica* Control Techniques under Farmer Management. *Experimental Agriculture* 39: 99-108.

Shank R. (1996). The parasitic weed and its relation to poverty. [http://www.africa.upenn.edu/EUE/striga 396.html] Site visited on 2/9/2017.

Sheriff, A.M. and Parker, C. (1988). Effect of nitrogen and organic matter on *Sorghum bicolor* Moench and *Striga hermonthica* Benth. *Ethiopian Journal of Agricultural Science* 8: 19- 35.

Showemimo, F.A. and Kimbeng, C.A. (2005). Genetic studies of sorghum cultivars under *Striga* infestation in Northern Guinea Savannah of Nigeria. *Crop protection* 38(2): 1-6.

Showemimo, F.A., Kimbeng, C.A and Alabi, S.O. (2002). Genotype response of sorghum cultivars to nitrogen fertilization in the control of *Striga hermonthica*. *Crop Protection* 21: 867- 870.

Simier, P., Constant, S., Degrande, D., Moreau, C., Robins, R.J., Fer, A. and Thalouarn, P. (2006). Impact of nitrate supply in C and N assimilation in the parasitic plant *Striga hermonthica* (Del.) Benth (Scrophulariaceae) and its host *Sorghum bicolor* L. *Plant Cell Environment* 29: 673–681.

Sjogren, H., Shepherd, K. D and Karlsson, A. (2010). Effects of improved fallow with *Sebaniasesban* on maize prouctivity and *Striga hermonthica* infestation in Western Kenya. *Journal of Forestry Research* 21(3): 379-386.

Smaling, E.M.A., Nandwa, S.M., Prestele, H., Roetter, R. and Muchena, F.N. (1992). Yield response of maize to fertilizers and manure under different agro-ecological conditions in Kenya. *Agricultural Ecosystems and Environment* 41: 241-252.

Smaling, E.M.A., Stein, A. and Sloot, P. H. M. (1991). A statistical analysis of the influence of *Striga hermonthica* on maize yields in fertilizer trials in Southwestern Kenya. *Plant Soil* 138: 1- 8.

Stals, H. and Inze, D. (2001).When plant cells decide to divide. *Trends Plant Science* 6: 359– 364.

Stemler, A.B., Harlan, J.R. and Dewet, J. M. (1975). Evolutionary history of cultivated sorghum [*Sorghum bicolour* (L).Moench] of Ethiopia. *Bulletin of the Torrey Botanical Club* 102: 325- 333.

Sun, Z., Matusova, R and Bouwmeester, H. (2007). Germination of *Striga* and Chemical Signaling Involved: A Target for Control Methods. World Scientific Publishing Co. Pte. Ltd., Singapore. 47– 60.

Tarfa, R.A., Kuresh, I., Kuchinda, N.C., Shinggu, A., Omolehin, R.A., Alabi, S.O. and Ado, S.G., (2001). Influence of initial soil physico-chemical properties on *Striga* and maize crop parameters under improved management practices. In: *The Proceedings of international workshop on Maize Revolution in Westand Central Africa West and Central Collaborative Maize Research Network*. (Edited by Badu-Apraku, B., Fakorede, M.A.B., Ouedraogo, M., Carsky, R.J and Menkir, A.), IITA, Cotonou, Benin Republic. 303– 313.

Taye, and Tesfaye, M. (2013). Intergrated *Striga* Management in Sorghum in Ethiopia and Tanzania Project. In: *An overview and planning meeting. Proceedings of EIAR*, Ethiopia, 4-7 June, 2013, Imperial Hotel, Kisumu, Kenya. 1- 44.

Teka, H. B. (2014). Advance research on *Striga* control. *African journal of plant science* 8(11): 492- 506.

Temam, H. (2006). Distribution of two *Striga* species and their relative impact on local and resistant sorghum cultivars in east Ethiopia. *Tropical Science* 46: 147- 150.

Templeton, G.E. (1982). Status of weed control with plant pathogens. In: *Biological Control of Weeds with Plant Pathogens*. (Edited by Charudattan, R. and Walker, H. L.), Wiley, New York. 29- 44.

Tesso, T., Zenbaba, G., Aberra, D. and Ejeta, G. (2007). An integrated *Striga*management option offers effective control of *Striga*in Ethiopia. In: *Integrating New Technologies for Strigacontrol*: *Towards Ending the Witch-hunt*. (Edited by Ejeta, G. and Gressel, J.), World Scientific Publishing Co., Singapore. pp. 199-212.

Thomas, G. W. (1982). Exchangeable cations. In: *Methods of Soil Analysis, part 2, 2nd edition, Chemical and Mineralogical Properties, Agronomy Monograph No. 9*. (Edited by Page, L. A. Miller, R. H. and Keeny, D. R.), American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin. pp. 595-624.

Tisdale, S. L., Nelson, W. L. and Beaton, J. D. (1993). *Soil fertility and fertilizers*.6th Edition.Prentice Hall, Upper saddle. New Jersey. 305- 319.

TMA. (2014). TMA Weather forecast; ISO 9001:2008 Certified (in Aeronautical Meteorological Services). [http://www.meteo. go.tz/index.php] Site visited on 7/6/2015.

Udom, G.N., Babatunde, F.E. and Tenebe, V.A. (2007). Suppression of witch-weed (*Strigahermonthica*) in sorghum: cowpea mixture as affected by cowpea varieties and planting patterns. *International Journal of Agricultural Research* 2: 268-274.

Undersander, D. (2003). Sorghums, Sudangrasses, and sorghum-Sudan hybrids. Univ. of Wisconsin Focus on Forage 5:5, Madison. [http://www uwex.edu/CES/crops/uwforage/SorghumsFOF.htm]. Site visited on 26/2/ 2016.

United Republic of Tanzania, Ministry of Agriculture, Food security and Cooperatives. (2010). Statistics Report. [http://www.kilimo.go .tz/agricultural %20statistics/...2010/4 Text%20Report.doc] Site visited on 29/5/2015.

USDA, (2003). Production Estimates and Crop Assessment Division Foreign Agricultural Service. [usda.mannlib.cornell.edu/usda/fas/oilseed-trade/.../2003/oilseed-trade-05-01-2003.pdf] Site visited on 20/9/2016.

USDA. (1995). *Soil Taxonomy*. A basic system of soil classification for making and interpret soil surveys. Agriculture Hand book no. 436. Washington D.C. 754pp.

Vallance, K.B. (1950). Studies on the germination of the seeds of *Striga hermonthica*: the influence of moisture treatment, stimulant dilution, and after-ripening on germination. *Annals of Botany* 14: 347- 363.

Van Delft, G.J., Graves, J.D., Fitter, A.H. and Van Ast, A. (2000). *Striga* seed avoidance by deep planting and no-tillage in sorghum and maize. *Journal of Pest Management* 46: 251- 256.

Van Mourik, T.A. (2007). *Striga hermonthica* seed bank dynamics: process quantification and modelling. Dissertation for Award of Degree of Doctor of philosophy (Ph.D.) at Wageningen University, Wageningen, Netherlands. 135pp.

Vogt, W., Sauerborn, J. and Honisch, M. (1991). *Striga hermonthica*, distribution and infestation in Ghana and Togo on grain crops. In: *Proceedings of the 5th International Symposium of Parasitic Weeds*. (Edited by Ransom, J. K. *et al*.), CIMMYT, Nairobi Kenya. pp. 372- 377.

Weber, G., K. Elemo, A. A., Lagoke, S.T.O and Oikeh, S. (1995). *Striga hermonthica* in cropping systems of the Northern Guinea Savanna. Resource and Crop Management Research Monograph No. 19 (Ibadan, Nigeria: International Institute of Tropical Agriculture), 27pp.

WFP, FAO and IFAD. (2012). The State of Food Insecurity in the World 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. [www.fao.org/docrep/016/i3027e/i3027e.pdf] Site visited on 27/05/2015.

WFP. (2007). Executive brief: Tanzania Comprehensive Food Security and VulnerabilityAnalysis.[http://documentswfp.org/stellent/groups/public/doc uments/ena/wfp119800.pdf] Site visited on 25/4/2015.

Williams, C.N. (1961b). Tropism and morphogenesis of *Striga* seedlings in the host rhizosphere. *Annals of Botany* 25: 407- 414.

Wood, D. and Lenne', J. (2001). Nature's field: A neglected model for increasing food production. *Outlook on Agriculture* 30: 161-170.

Wortmann, C.S., Mamo, M. Abebe, G., Mburu, C., Kayuki, K.C., Letayo, E. and Xerinda, S. (2006). The Atlas of Sorghum Production in Five Countries of Eastern Africa University of Nebraska -Lincoln, Lincoln, USA.[http:// www.infonet-biovision.org.sorghum] site visited on 15/5/2015.

Yoder, J.I. (2001). Host plant recognition by parasitic scrophulariaceae. *Current Opinion in Plant Biology* 4: 359- 365.

Yohanna, M. K. (2014). Effect of time of nitrogen application on the performance of maize (*Zea mays* L.) varieties at Mubi, Northern Guinea Savanna of Nigeria. *American Journal of Research Communication* 2(2): 71- 81.
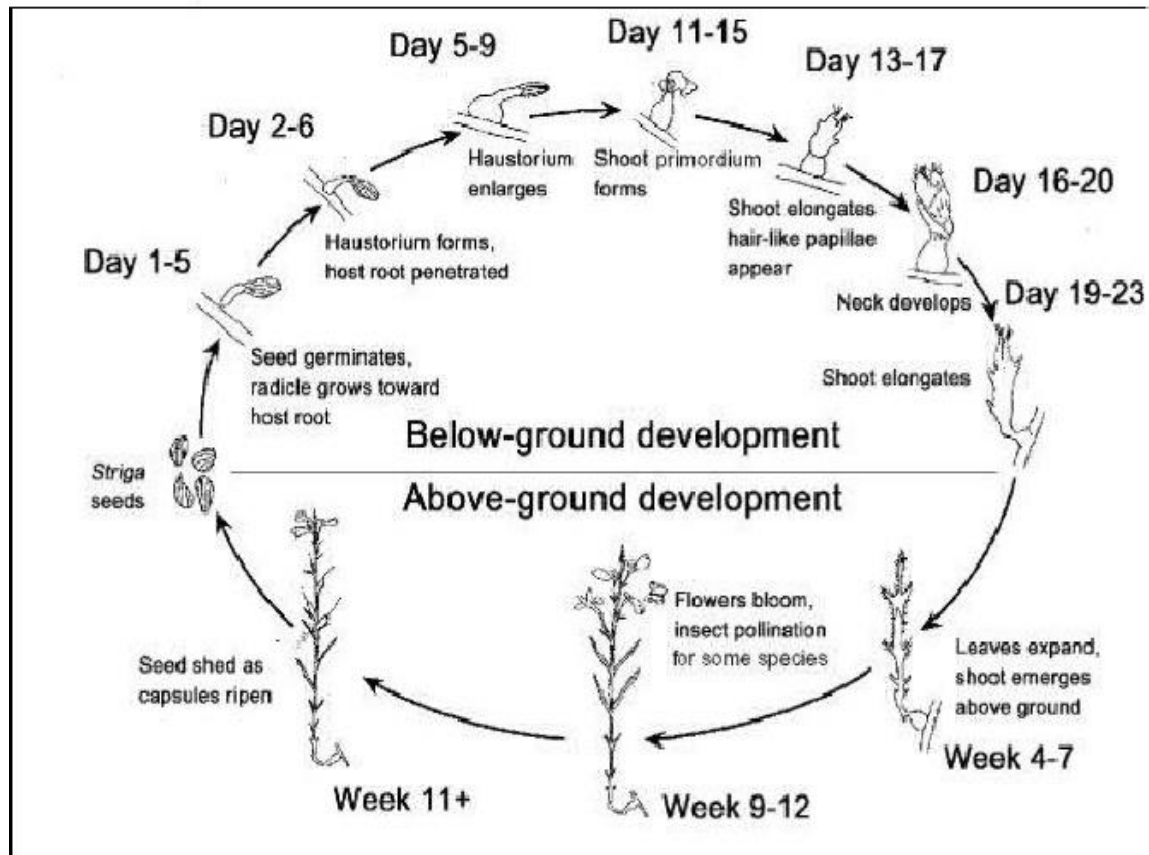
APPENDICES

Appendix 1: Domain Striga species in Tanzania.
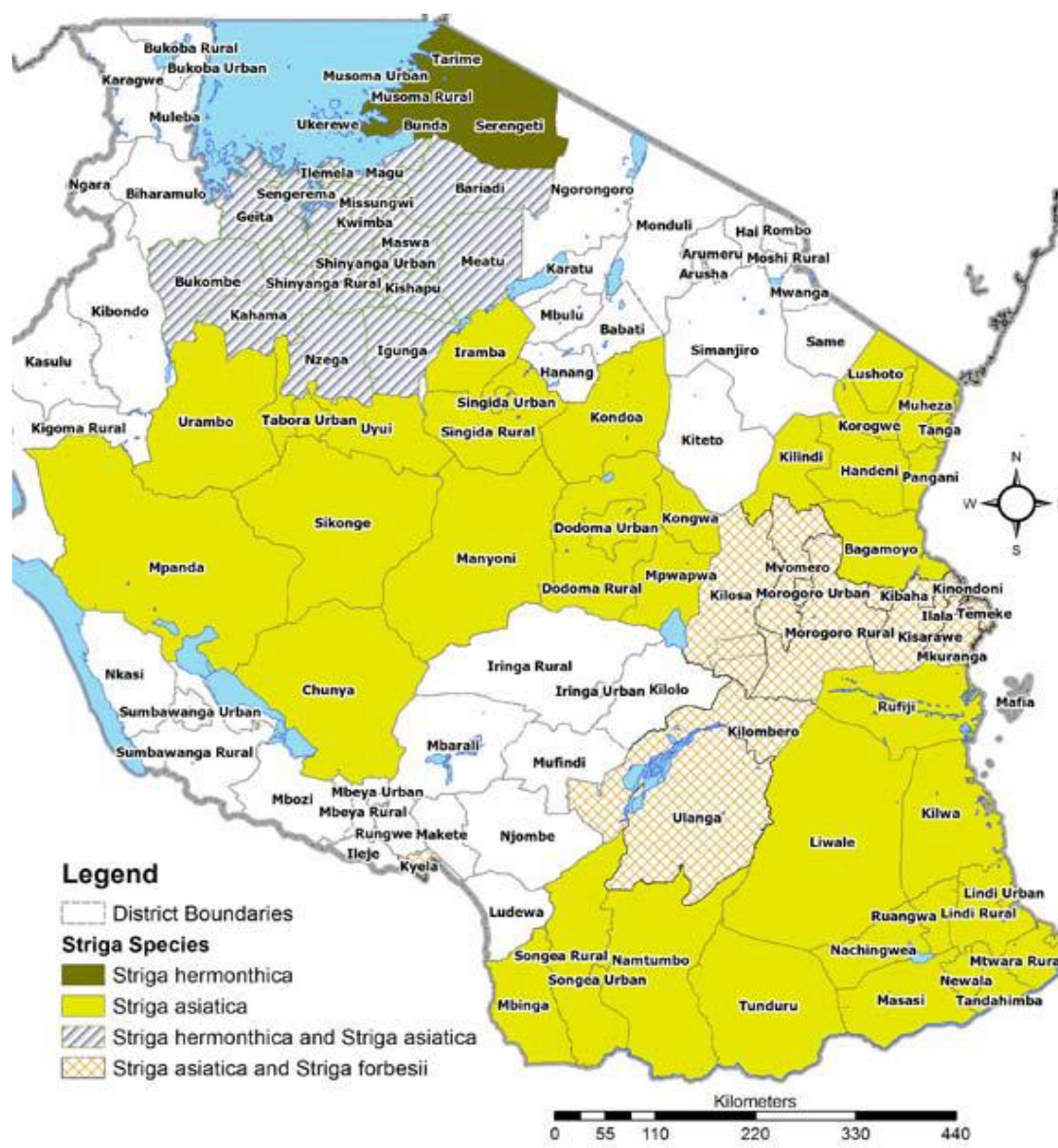
Source: Mac Opiyo *et al.*, (2009)**.**

Appendix 2:.Extent and Severity of Striga Infestation in Tanzania.

Source: MacOpiyo *et al*., (2009).

Appendix 3: General life cycle of *Striga* weeds.

Source: IITA, (1997).

Appendix 4: Mean daily rainfall for 2015/16 cropping season at Hombolo

Kadi No. 6a (Rev.9/10)

MAMLAKA YA HALI YA HEWA TANZANIA

S.L.P 3056 DAR ES SALAAM

TAKWIMU ZA MVUA ZA MWAKA

JINA LA KITUO: HOMBOLO AGROMET   MWAKA: 2016

NAMBA YA KITUO: 9535019

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DES**
1	**17.1**	0.0	0.0	**25.7**	0.0							
2	0.0	**30.0**	0.0	**8.5**	0.0							
3	0.0	**1.7**	0.0	**21.0**	0.0							
4	0.0	0.0	0.0	**88.0**	0.0							
5	0.0	**2.8**	0.0	0.0	0.0							
6	0.0	**15.6**	0.0	**20.3**	0.0							
7	0.0	**5.0**	0.0	0.0	0.0							
8	0.0	**9.7**	0.0	**2.3**	0.0							
9	0.0	**7.1**	0.0	0.0	0.0							
10	**32.2**	0.0	**3.6**	0.0	0.0							
11	**33.7**	**3.1**	0.0	0.0	0.0							
12	**47.8**	**8.9**	0.0	0.0	0.0							
13	**11.0**	0.0	0.0	0.0	0.0							
14	0.0	**9.8**	0.0	0.0	0.0							
15	0.0	0.0	0.0	0.0	0.0							
16	0.0	0.0	0.0	**4.4**	0.0							
17	**46.1**	0.0	0.0	**4.8**	0.0							
18	**32.1**	0.0	**3.9**	0.0	0.0							
19	0.0	**0.6**	0.0	0.0	0.0							
20	**10.9**	0.0	0.0	0.0	0.0							
21	**1.4**	0.0	0.0	0.0	0.0							
22	**44.4**	0.0	0.0	0.0	0.0							
23	**11.7**	0.0	**25.1**	0.0	0.0							
24	**1.7**	0.0	0.0	0.0	0.0							
25	0.0	0.0	**6.2**	**32.2**	0.0							
26	0.0	0.0	0.0	0.0	0.0							
27	**13.7**	0.0	0.0	0.0	0.0							
28	0.0	0.0	0.0	0.0	0.0							
29	0.0	0.0	0.0	0.0	0.0							
30	**21.5**	-	0.0	0.0	0.0							
31	**2.5**	-	0.0	-	0.0							
Mvua ya Tar.1	FEB 0.0	MAR 0.0	APR **25.7**	MAY 0.0	JUN 0.0	JUL	AUG	SEP	OCT	NOV	DES	JAN
Jumla	*327.8*	*94.3*	*38.8*	*207.2*	*0.0*							
Jumla Kuu	**422.4**	**516.7**	**555.5**	**762.7**	**762.7**							
Siku ngapi	15	10	5	9	0							
Wastani												

Source: Stephen, S.Z. personal communication, (2016).

Appendix 5: Mean monthly rainfall for 2009 to 2016 cropping season at Dodoma
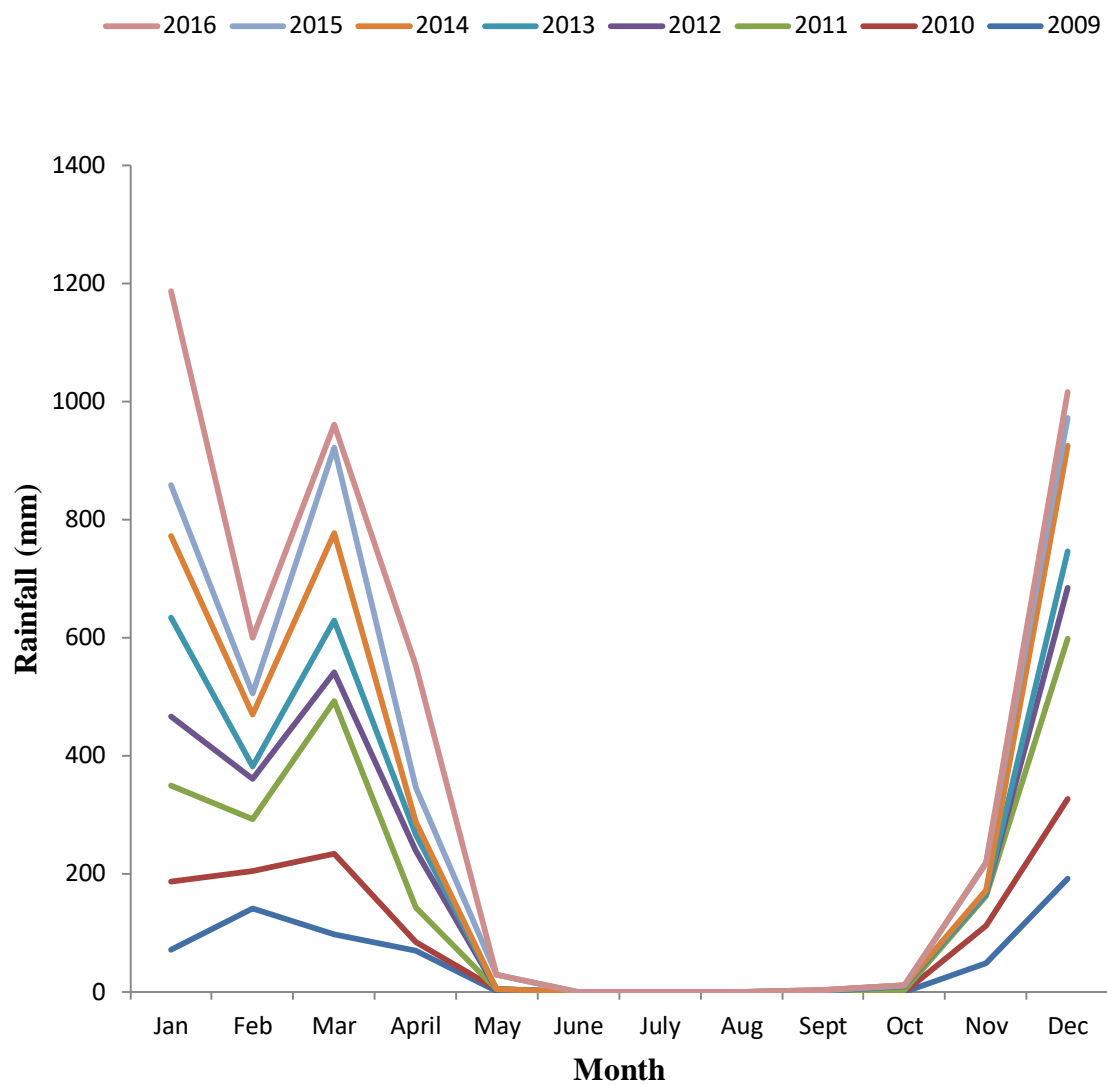
Source: Stephen, S.Z. personal communication, (2016).

Appendix 6: Observation of emerged *Striga* shoots at Hombolo at 10 WAP