MANAGEMENT OPTIONS FOR RICE STEM BORERS IN IRRIGATED LOW LAND RICE ECOSYSTEMS IN TANZANIA

BONAVENTURE JANUARY

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE MOROGORO, TANZANIA.

2020

EXTENDED ABSTRACT

Studies were carried out to establish the role and significance of rice stem borers as pests of rice crop in irrigated low land rice ecosystems in Tanzania; and to evaluate the effectiveness of some management options against the pest. A survey by means of structured questionnaire was initially used to assess the farmer's perception on rice stem borers and their management practices in three wards of Kilombero district in Morogoro Region, namely, Mkula, Sanje and Signali. This was followed by diagnostic survey to assess the incidences and population dynamics of rice stem borer species and the naturally existing parasitoids in farmers' fields. Farmers reported several insect pests such as stem borers, white flies, leaf rollers and grasshoppers as common insect pests infesting rice crop of which stem borers was reported as most injurious. Most farmers (78.2%) applied chemical insecticides susch as Kung'fu, Karate and Amekan against rice insect pests particularly stem-borers. Only a small proportion (18.5%) of farmers used cultural methods which include burning of crop residues, removal and bury of infested straws, and split application of nitrogen ferliizer in combating stem borer problem. Two stem borer species; *Chillo* sp and *Sesamia calamistis* were identified to exist in Kilombero valley with *Chillo* sp being most abundant (79.24 - 92.05%) compared to *S. calamistis* (7.97 - 20.77%). One parasitoid, *Cotesia flavipes* of the family Braconidae was found parasitizing the stem borer larvae in the study area. The tested management options against rice stem bore included cultural methods (adjustment of spacing and nitrogen fertilizer), chemical methods (synthetic insecticides) and biological control methods (fungi based biopesticides and botanicals). The efficacy of biological and chemical control methods were tested under controlled environment (laboratory and in screen house) at Sokoine University of Agriculture by artificial infestation using first instar larvae of *Chilo partellus*. The experiments involved six treatments which included two commercial fungi based biopesticides (*Beauveria bassiana* and *Metarhizium anisopliae*), two botanical extracts (*Neorautanenia mitis* and *Derris eliptica*), one of the currently recommended synthetic insecticide, Amekan 344EC (Cypermethrin 144g/l + Imidacloprid 200 g/l), and untreated control (distilled water). The use of fungi based biopesticides and botanical extracts led to slightly lower stem borer mortality that ranged from 58% to 78% compared to 94% due to Amekan 344EC (positive control) under laboratory conditions. Results from screen house experiments (when compared with the negative control) indicated a significant (F = 11.94; df = 5, 15; $P < 0.001$) reduction of *C. partellus* damage incidences by 60.62% and 70.70% for dead heart and white head respectively when *M. anisopliae* was used while 61.86% and 51.17% dead hearts and white head, respectively were attained with *B. bassiana*. *Neorautanenia mitis* reduced dead heart and white heads by 53.14% and 49.28% respectively whereas 45% and 42.01% reduction in dead heart and white head, respectively were attained when *D. elliptica* was applied. Comparison of rice yield attained using Amekan 344EC (treated control) to control stem borer suggested percentage reduction of yield losses by 89.31% using *M. anisopliae*; 80.3% using *B. bassiana*; 72.42% using *N. mitis* and 67.77% using *D. elliptica*. Grain yield of 4.85 t ha^{-1} and 5.16 t ha^{-1} recorded in botanicals, 5.73 t ha^{-1} and 6.39 t ha^{-1} in fungi based biopesticides treated plots was higher than 2.84 t ha-^{1} recorded in un-treated (negative) control plots. The tested cultural control methods which involved the use of nitrogen fertilizer and spacing against rice stem borers in field experiments at Signali, Mkula and Sanje wards suggested a significant ($P < 0.05$) increase in rice stem borer’s damage incidences with increase in nitrogen quantity and decrease in plant population. Nitrogen significantly increased dead hearts by 4.8%, white heads by 2.8% and stem borer larvae density from 0 to 5.6 larvae/m^2. Decreasing the planting density significantly increased dead hearts by 4.7%, white heads by 2.7% and stem borer larvae density from 0 to 5.4

larvae/m^2. Rice yield increased with increase in nitrogen dosages to attain the optimum level at 80 Kg N ha^{-1} at plant population of 250 000 beyond which no further increase in yields was recorded. Conclusively, this study revealed two rice stem borer species, *Chilo* sp and *Sesamia calamistis* as major problem in Kilombero valley. One parasitoid, *Cotesia flavipes* was found to exist in all study areas, which is an important biological control of the two stem borer species, and therefore need to be preserved. The two botanicals, *D. elliptica* and *N. mitis* at the rate of 10mil/l have been proved to be effective in the control of stem borers. Therefore efforts should be made to explore standardization and packaging for farmers to get them at easy. The two fungi based biopesticides; *M. anisopliae* and *B. bassiana* at the rate of 1ml/l have proved to be effective against stem borer problem. Preliminary of use should be by exploring the locally available biopesticides and of low cost. Application of nitrogen fertilizer at the rate of 80 Kg N ha^{-1} and spacing of 20 cm x 20 cm were optimum for obtaining high rice yield with minimal stem borer infestation, therefore should be encouraged to be used for management of rice stem borers as alternative to synthetic insecticides.

DECLARATION

I, Bonaventure January, do hereby declare to the Senate of Sokoine University of Agriculture that, this thesis is my own original work done within the period of registration and has never been submitted, nor concurrently being submitted for a degree award in any other institution. All sources of information used in the preparation of this thesis are indicated by reference.

24.08.2020

…………………………..…   ……………………….

Bonaventure January   Date

(PhD Candidate)

The above declaration is confirmed by

24.08.2020

………………………………….   ……………………….

Dr. G. M. Rwegasira   Date

(Supervisor)

24.08.2020

………………………………….   ……………………….

Dr. Tadele Tefera   Date

(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENTS

I thank the Almighty God who is the entire source of knowledge and wisdom for grace, salvation and blessings.

I would like to express my deep gratitude to my supervisors, Dr. G. M Rwegasira (SUA) and Dr. Tadele Tefera (ICIPE) for their guidance, advice, encouragement and contructive criticism, which had valuable contribution to the completion of this work.

I would also like to thank the Agricultural officers at Signali, Mkula and Sanje wards in Kilombero district for their assistance in data collection during the survey and field experimentation. Respondents during the survey the survey are acknowledged for willingly accepting to be interviewed.

The International Centre of Insect physiology and Ecology (ICIPE) supplied me with some research materials for both laboratory and screen house experiments and Real IPM Company supplied me with biopesticides for experimentation.

I am grateful to Dr. Emmanuel Mrema for his criticism and sound comments during thesis write up. I also extend my sincere appreciation to the Academic staff of the Department of Crop Science and Horticulture at SUA for helping me in many ways during my studies. My gratitude also goes to my family and my parents (Late Father January (R.I.P) and Mrs January), my sister (Epiphania), my brothers (Jerome, Victor, Wenseslaus and Late Silvestry (R.I.P)) for their prayers and encouragement during my study.

This study was funded by USAID through Feed the Future IPM Innovation Lab, Virginia Tech, Cooperative (Agreement No. AID-OAA-L-15-00001).

DEDICATION

This thesis is dedicated to my beloved Wife Levina, my parents; January Lamshaba and Fausta January, my children; Witness, Brianna and Briella and every member of the family for supporting me in my career.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

%	Percent
<	Greater than
>	Smaller than
≤	Less than or equal
≥	Greater than or equal
BRRI	Bangladesh rice research institute
BT	*Bacillus thuriningensis*
CIMMITY	International maize and wheat improvement centre
CRD	Completely randomized design
C.V	Coefficient of variation
DAP	Diammonium phosphate
DAT	Days after transplanting
DH	Dead heart
EC	Emulsfiable concentrate
FAO	Food Agriculture Organization
GPS	Geographical position system
g/L	Gram per litre
ICIPE	International centre of insect physiology and ecology
IPM	Integrated pest management
IRRI	International Rice Research Institute
ISU	Iowa State University
LSD	Least significant difference
MAFSC	Ministry of Agriculture, Food Security and cooperatives

m.a.s.l	Meter(s) above sea level
mg	Milligram(s)
ml	Milliliter(s)
mm	Millimeter(s)
cm	Centimeter(s)
MOP	Muriate of Potash
N	Nitrogen
No.	Number
NPK	Nitrogen-phosphorus-potassium
ns	Not significant
^{O}C	Degree Celsius
P	Probability
P	Phosphorous
PH	Potential hydrogen
RCBD	Randomized Complete Block Design
RH	Relative humidity
RLD	Rural live hood development
SDW	Sterile distilled water
SNK	Student Newman Keuls test
SPAD	Soil plant analysis development
SUA	Sokoine University of Agriculture
TN	Total Nitrogen
TSP	Triple super phosphate
URT	United Republic of Tanzania
WH	White head

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population. The crop influences the economic livelihood of several billion people (UNDP, 2010; FAO, 2015). Despite the high demand for rice in Tanzania, yield remains low in the range of 1–1.79 tonnes/ha as compared to potential yield of 6–10 tonnes/ha reported in Asia rice grown countries such as Vietnam, China, Thailand and Pakistan due to various constraints including insect pests (FAO, 2015). Tanzania is among major producers and consumers of rice in sub-Saharan Africa. It is the second most cereal crop cultivated in Tanzania after maize where percapital consumption ranges from 25 - 30 kg annually (Kibanda, 2008. It is cultivated in three agro-ecologies which include rain fed low land, irrigated low land and rain fed upland (Mghase *et al*., 2010). Lowland conditions (irrigated and rain fed) account for about 80% and upland for about 20% of the production (Kanyeka *et al*., 2007). The population in Tanzania is currently growing at a rapid rate of 2.8% annually (URT, 2013) and self-sufficiency ratio for food is 81% where as the recommended ratio according to FAO is 120% (MAFSC, 2009). This results in a continuous increase in demand for rice and other food hence the need to increase production (Kanyeka *et al*., 2007.

1.2 Constraints of Rice Production

Rice production may be increased in many regions by high yielding varieties, improved water and soil management, and fertilizer application. An increased yield potential of rice, however is often associated with several constraints including higher vulnerability to pests attack leading to increasing absolute losses and loss rates (Oerke *et al*., 2004). An important constraint for achieving higher rice yield is losses caused by pests (Huang *et al*., 2014). Globally, an average of 35% of potential rice crop yield is lost during pre-harvest due to number of pests (FAO, 2015). Major pests such as blast, sheath blight, bacterial blight, plant hoppers, leaf folder and stem borers are major concerns in rice paddy fields (Huang, 2014).

1.3 Rice Stem borer Species

There are about 20 species of rice stem bores reported worldwide amongst which only four are of economic importance in Africa rice (Ogah *et al*., 2013). The species includes *Chilo* spp, *Diopsis* spp, *Maliarpha separatella* (Ragonot) and *Sesamia calamistis* (Hampson). In Tanzania, four rice stem borers have been reported of which three species them are from order Lepidoptera and one from order Diptera. These include lepidopteron, white stem borer (*M. seperatella*), African pink stem borer (*S. calamistis*) and Spotted stem borer (*Chilo partellus*, Swinhoe) and a Dipteran, stalked-eyed borer (*Diopsis thoracica* Westwood) (Banwo, 2002). Very few studies exist on rice insect pests in Tanzania (Banwo *et al*., 2001; Leonard and Rwegasira, 2015; January *et al*., 2018a).

1.4 Lepidopteron Stem borers

Among the insect pests, the lepidopteron stem borers have been reported as most injurious (Amaugo and Emosairue, 2003). When the stem borers infest rice crop, they caused different injured symptoms depending on the growth stage of rice during infestation. Larva is the only destructive stage where it finds suitable food to be used up to the end of pupa stage during which the pest protects itself from the enemies as well as adverse environmental condition (Nwilene *et al*., 2008). The older stem borer larvae feed inside the stem and vascular tissues while the young larvae feed within the leaf sheath (Alinia *et al.,* 2000). When infestation occurs during vegetative stage (before panicle initiation) it results into dead heart symptom while during reproduction stage (after panicle initiation) results into development of white head symptom (Pathak, 1968; Dale, 1994; Moche *et al*., 2015).

1.5 Management of Stem borers

1.5.1 Cultural Control

Cultural control is considered as one of the most appropriate and economical method of stem borer management for resource poor farmers in Africa (Rami *et al.*, 2002). It is among the oldest traditional and environmental friendly methods which are also regarded as a key defense against pests (Dent, 1991). It is useful when other control tactics becomes irrelevant for various reasons such as being very expensive such that poor farmers cannot afford or sometimes are not available and when other control measures are not fully successful (Polaszek, 1998). These include adjustment of soil macro-nutrients such as nitrogen and phosphorus and management of plant spacing. Despite the fact that cultural control practices for stem borer seems promising, they have scantly been tested and adopted by many farmers in Africa (Rami *et al*., 2002).

Adjustment of nitrogen doses to rice crop is among the cultural means of reducing stem borer damages. Nitrogen content in plants has a bearing on stem borer preference, infestation and subsequent damages (Sarwar, 2011). For example in South Africa, where *Eldana saccharina* is a problem on sugarcane, a reduction in nitrogen-fertilization rate from 50 kg per hectare to 30 kg per hectare has been recommended for the control of that pest (SASA, 1994) whereas Rami *et al*. (2002) reported a reduction of sorghum yield losses due to *M. separatella* from 20% with no fertilizer to 11% with 120 kg of nitrogen per hectare in Nigeria. In Tanzania, Ali *et al*. (2006) reported stem borer density and percentage of bored internode per plant to increase with increase in nitrogen levels in maize crop. The interactive effect of stem borers and nitrogen fertilizer on rice have scantly been explored despite the fact that a knowledge on this would contribute to fertilizer use efficiency while minimizing stem borer infestation for increased productivity of rice.

Alteration of spacing can also play role in minimizing stem borer damages by affecting the dynamics of insect pests. Funderburk *et al*. (1993) documented that changing the abundance of vegetation within an agro-ecosystem could bring about the alteration of pest dynamics. Plant population tends to increase at closer spacing and decreases to the wide spacing, thus affects abundance and population of insect pests (Degri *et al*., 2014). Ogah (2005) reported rice planted at 10-cm x 10-cm had the highest percent damage incidence by African rice gall midge compared with those planted at spacing of 20-cm x 20-cm and 30-cm x 30-cma. The effect of such factors particularly for stem borer damage incidences in rice crop has never been comprehensively documented.

1.5.2 Biological Control

1.5.2.1 Fungi based Biopesticides

The use of biopesticides particularly fungi based biopesticides is another environmentally friendly method in combating stem borer problem. This is pest population leveling process whereby the population of one fungi species suppresses the population of another species through pathogenicity (Noorhosseini *et al*., 2010). Entomopathogenic fungi are among the first organism to be used in the control of agricultural pests (Hailu *et al*., 2012). About 90 genera and 700 species of fungi representing a large group of entomopathogens (*Metarhizium* spp, *Beauveria* spp and *Verticillium* spp.) have been reported to be pathogenic (Manisegaran *et al*., 2011). Among the entomopathogenic fungi, two species, *Beauveria bassiana* (Balls.) Vull and *Metarhizium anisopliae* (Metsch.) Sorokin have been given high attention thereby encouraging several scientific studies and formulations in insect pest management systems (Faria, 2001). Studies by Hailu *et al*. (2012) in laboratory based experiments revealed many strains of *M. anisopliae* and *B. bassiana* isolates to have high level of mycosis against pink stem borer (*S. calamistis*) in sugarcane.

Fukon *et al*. (2014) reported reduction in fruit damage by fruit borers (*Helicoverpa armigera* Hubner) by 89% and 87% as compared to control when tomatoes were sprayed with commercial *B. bassiana* and *M. anisopliae,* respectively under field conditions in India. Further the study by Teshome and Tefera (2009) has revealed the potential of *B. bassiana* and *M. anisopliae* in control of storage pests of maize (*Sitophyllus zeamais* Mostch) in Kenya. In Tanzania, the knowledge on the use and efficacy of bio-control agents particularly fungi based biopesticides for stem borer controls are generally lacking.

1.5.2.2 Natural Enemies

The use of natural enemies such as parasitoids has also been reported to be an important safe approach in reducing stem borer infestation. Parasitoids are among the natural enemies which are important parasites of insect egg or larval stages. There are more than 95 parasitoids known to be associated with stem borers (Maliafiya *et al*., 2009). However, previous studies focused on identification and parasitism of stem borer in two cereal crops of upland conditions, maize and Sorghum (Niyibigira *et al*., 2001; Maliafiya *et al*., 2010). These have particularly focused on one parasitoids, *Cotesia flavipes* Cameron in Kenya (Maliafiya *et al.,* 2010); three parasitoids, *C. flavipes, Chelonus* spp and *Syzeuctus ruberrimus* Benoit in Tanzania.

These parasitoids can be maintained in the field through habitat management or avoiding application of extensive range of toxic insecticides (Togola *et al*., 2020). The botanicals and biopesticides are among naural or less extensive insecticides user friendly to natural enemies such as paraitoids (January *et al*., 2018b). The botanicals can affect the borers through repellent or antifidant effect (Ogah *et al.,* 2011), and biopesticides through mortality of the borer laravae, while keeping the parasiotoid less or not affected (Aw and

Hue, 2017). Information on parasitoids associated with these stem borers in low land rice ecology are scarce.

1.5.2.3 Utilization of Synthetic Sex pheromones

This involves catching of adult male moths using sex pheromone baited traps (Su *et al*., 2003). These baited traps are essential for monitoring moth population of Lepidopteron stem borer species (Abdulla, 2007). For example, SU *et al*. (2003) have reported Z-11-hexadecenal, Z-13-octadecenal and Z-9-hexadecenal as common sex pheromones used in China which are baited in traps to control stem borers in rice fields. Charudattan *et al*. (2006) reported that mass trapping of stem borers using sex pheromones is unlikely to provide satisfactory control but mating disruption is more likely to be effective. However, the efficiency of mass trapping by sex pheromone in large field is uncertain.

1.5.2.4 Use of Botanicals

The efficacies of botanicals have been largely demonstrated in insect management and have been advocated for use by resource poor farmers (Khorram *et al*., 2011; Mulungu *et al*., 2011). Mulungu *et al*. (2007) reported a significant reduction in beans damage by bean bruchid (*Zabrotes subfasciatus* Boheman) when common beans (*Phaseolus vulgaris* L.) were treated with Nyongwe (*Neorautanenia mitis* Verdic), Pyrethrum grist (*Chrysenthemum cinerariaefoliun* Boccone) and garlic (*Allium sativum* L.) extracts before storage. Visetson and Milne (2001) reported high toxic effects of rotenone extracts from Derris plant (*Derris elliptica* Bench) to larva of Diamond back moth (*Plutella xylostella* Linn) in Chinese kale. Further studies by Sangmaneedet *et al*. (2005) reveals high mortality of pig fly (*Faria canicularis* L.) larvae when treated with fresh and dry *D. elliptica* powder. Also Muro (2010) reported high mortality of melon fly (*Bactocera cucurbitae* Conquillet) using *D. ellitica* bites in water melon. The current study, reported the efficacy of the two botanicals commonly found in Tanzaniawchich includes; *D. elliptica* and *N. mittis*.

Derris elliptica is commonly known locally as Tuba or Derris plant contains rotenone, a well-known bio-active compound that has the potential to be used as bio-pesticide (Zubairi *et al.*, 2014) and it is commonly found in tropical forests (Muro, 2010). The ‘tuba’ plant is a woody plant which grows along the ground, crawling and climbing to other plants. It needs at least 75% moisture and a temperature of 25 oC to live (Muro, 2010). The rotenone contained in *D. elliptica* has come of interest because of its selectivity and low environmental hazard. Rotenone is highly toxic to insects but relatively non-toxic to plants, mammals and honey bees (Suraphon and Manthana, 2001). Rotenone is extremely active as contact and stomach poisons against many crop pests such as Mexican bean beetles, apple and pea aphids, maize stem borers and household pests (Parmar *et al*., 2001). Besides rotenone, other bioactive compounds found in *D. elliptica* includes derrid, anhydroderrid, derrin, tubotoxin, and tubain (Visetson and Milne, 2001; Zubairi *et al*., 2014).

Neorautanenia mitis is a leguminous subshrubby plant found growing in rocky soils and it is native to the Central, South and West Africa (Burkill, 1995). It is commonly known as Nyongwe and it is found in tropical forests (Mulungu *et al*., 2007). Root of *N. mitis* is reputed for its insecticidal and insect-repellant properties, treatment of syphilis, female frigidity and skin infections like scabies and rashes (Leticia *et al*., 2008). Rautandiol, neoduline, neotenone, pachyrrhizine and 12a-hydroxylrotenone are know bioactive compounds of this plant (Lasisi and Adesomoju, 2015). The mode of action of of these bioactive compounds contained in *N. mitis* to insect pests are mainly through contact and stomach poisons (Lasisi and Adesomoju, 2015). Despite the fact that *D. elliptica* and *N. mitis* have been proved to be effective against various insects, however their effectiveness agaist rice stem borers has never been evaluated.

1.5.3 Chemical Control

Chemical control is encouraged when all other control methods are deemed to be ineffective. Pesticides to be applied should be of low-toxicity and not harmful to other non-targeted species as well as humans (Abdulla, 2007). Most chemicals are used as insecticide granules which are applied to the standing water. It is recommended to apply pesticides when damage exceeds 10% and 5% dead heart and white head respectively, (Nwilene *et al*., 2008). Some of insecticides such as Fipronil, Carbofuran, Carbosulfan, Diazinon, Chlorpyrifos, Phenthoate and Quinalphos have been proved to be successful in stem borer control (Prasad and Gupta, 2012). On the other hand the use of insecticides in stem borer control has been discouraged due to disruption of environment and unaffordability to purchase the insecticides by small holder farmers (Ogah *et al*., 2011).

1.6 Problem Statement and Justification

Rice stem borers have been reported to attack several cereal crops causing considerable losses depending on the crop plant. For example, yield losses due to stem borer of up to 80% in maize have been reported in Kenya (Ampofo, 1986), up to 50% in sorghum in Ethiopia (Tefera, 2004) and 60% in African rice (Pathak and Khan, 1994). In Lake Zone Tanzania, the stem borers' incidences ranging from 0.56% to 7.57% and 0.34% to 2.89% for dead heart and white head respectively have been reported (Leonard and Rwegasira, 2015). However, little was known in Kilombero district prior this study.

Damages due to rice stem borers in Tanzania have been reported mainly in rain fed low land rice ecosystem where the crop is grown only once per year (Leonard, 2015). In irrigated low land rice ecosystem such as that of Kilombero district where rice is grown twice or thrice per year the problem could be high but substantial facts were to be established. Several stem borer parasitoids including *Cotesia* spp, *Dolichogenidea aethiopica* Wilkinson have been reported in maize and sorghum (Niyibigira *et al*., 2001). Similar or different parasitoids can be found in rice which can in future be used as important biological control. This important information was lacking under Tanzania contest.

To date, there are no recommended methods for management of rice stem borers in Tanzania. Insecticides have been used with some success in controlling stem borers elsewhere (Prasad and Gupta, 2012) but their harmful side effects on human health and the environment particularly the beneficial organisms suggests the need to explore alternative options. Understanding farmers' socio-economic factors, their knowledge, perceptions, and their current pest management practices are critical steps towards developing sustainable and cost effective integrated pest management (IPM) strategies (Alibu *et al.*, 2016). These has been reported to be usefully in Uganda for control of termites (Nyeko and Alubayo, 2005), in Ethiopia for control of sorghum stem borers (Tefera 2004), in Cameroon for management of maize stem borers (Oben *et al.*, 2015), and in Tanzania for management of Tomato leaf minor (Tuta absoluta Meyerick) (Materu *et al*., 2016). However, the information on farmers' knowledge and perceptions of rice stem borers is limited and farmers' efforts on managing this insect have been ineffective.

The attempts to control insects have changed over time from chemicals to natural control methods (Shahid *et al*., 2016)**.** Of the various natural control methods, biopesticides (Teshome and Tefera, 2009), botanical extracts (Mulungu *et al*., 2011) and cultural techniques (Rami *et al*., 2002) have received considerable attentions as a viable alternative to chemical pesticides. When these natural methods are used in place of conventional insecticides they can minimize environmental pollution, preserve non-target organisms such as natural enemies and delay insecticide induced pest resistance (Ogah *et al*., 2011).

Teshome and Tefera, (2009) have reported *M. anisopliae* and *B. bassiana* isolates as the most virulent biopesticides causing 84.4% to 98.3% mortality to maize weevil (*Sitophilus zeamais* Motschulsky) when tested in laboratory, but little was known on the efficacy of these biopesticides in the control of rice stem borers. The use of botanical extracts in management of insect pests as an alternative to synthetic insecticides have been reported in crop protection for many centuries (Prakash *et al*., 2008) but their potentials have not been fully evaluated. Mulungu *et al*. (2007) have reported the potential of *N. mitis* in controlling bean bruchid (*Zabrotes subfasciatus* Boh) whereas Muro (2010) has reported an increase in mortality of melon fly (*Bactocera cucurbitae* Concuillet) when using *D. elliptica* extracts. The potential of these effective botanicals in controlling the rice stem borers have not been reported.

The potential of cultural control practices in the management of rice stem borers have not been exploited by many African farmers (Rami *et al*., 2002). Limited access to the data from existing studies, despite their novelty, often leads to hesitation in the adoption of such practices. One such example is the limited information available regarding the influence of nitrogenous fertilizers and plant spacing in promoting or deterring damage by rice stem borers (Baidoo, 2004; Ogah, 2005; Ali, 2006; Wale *et al*., 2006). Understanding the interaction effects of spacing and nitrogen fertilizer with stem borers could improve the efficient of fertilizer use efficiency while controlling stem borers in order to increase the productivity of rice. The current study aims at assessing the effectiveness of cultural techniques (alteration of spacing and nitrogen fertilizer rates) coupled with fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and botanicals (*D. elliptica* and *N. mitis*) in controlling of rice stem borers under irrigated rice ecosystem. The study findings will guide the development of an effective IPM program for management of rice stem borers in Tanzania and elsewhere.

1.7 Objectives

1.7.1 Overall Objective

The main objective of this study was to generate knowledge that will contribute in minimizing yield losses associated with rice stem borers through eco-friendly management practices.

1.7.2 Specific Objectives

1. To assess farmers' perceptions of rice production constraints and stem borers management practices in Kilombero valley.
2. To evaluate the distribution of rice stem borers and their parasitoids in irrigated rice ecosystem
3. To quantify stem borer population and associated damages in farmers' fields in irrigated rice ecosystem.
4. To assess the effectiveness of *B. bassiana, M. anisopliae*, *D. elliptica* and *N. mitis* in controlling rice stem borers.

5. To determine the effects of spacing and nitrogen fertilizer on incidences of rice stem borers in irrigated rice ecosystem.

1.7.3 Organization of the thesis

The thesis is organized in publishable manuscripts format consisting seven chapters. Chapter one is general introduction of the thesis, chapter two, three, four, five and six consists publishable manuscripts. Chapter seven is general conclusion and recommendations.

References

Abdulla, N. P. (2007). Diversity of stem borer egg parasitoids and patterns of parasitism in Morogoro and Coast regions in Tanzania. Dissertation for Award of Msc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 70pp.

Ali, S. M. D. (2006). Effect of plant spacing on the incidence of major insect pests and their natural enemies in four rice varieties. Thesis for the Award of Masters Degree of Entomology at Bangladesh Agriculture University, Bangladesh. 68pp.

Ali, S. M. D. (2006). Effect of plant spacing on the incidence of major insect pests and their natural enemies in four rice varieties. Thesis submitted to the department of entomology Bangladesh Agriculture University for partial fulfilment of Masters of Science in Entomology. 68pp.

Alibu, S., Otim, M. H., Okello, S. E. A., Lamo, J., Ekobu, M and Asea, G. (2016). Farmer' s knowledge and perceptions on rice insect pests and their management in Uganda. *Journal of Agriculture 6*(3): 38.

Alinia, F., Ghareyazie, B., Rubia, L., Bennett, J and Cohen, M. B. (2000). Effect of plant age, larval age and fertilizer treatment on resistance of ab-transformed aromatic rice to lepidopterous stem borers and foliage feeders. *Journal of Economic Entomology* 93: 484 - 493.

Amaugo, G. O., Emosairue, S. O. (2003). The efficacy of some indigenous medicinal plant extracts for the control of upland rice stem borers in Nigeria. Tropical and Subtropical Agro-ecosystems. *Journal of Entomology* 2(3): 121-127.

Ampofo, J. K. O. (1986). Maize stalk borer (Lepidoptera: Pyralidae) damage and plant resistance. *Environmental Entomology* 15: 1124-1129.

Aw, K. M. S and Hue, S. M. (2017). Mode of infection of Metarhizium spp fungus and their potwential as biological control agents. *Journal of Fungi* 3: 30 - 45.

Baidoo, P. K. (2004). The role of silica and nitrogen in resistance of maize to stem borers. *Journal of Science and Technology* 24: 1.

Banwo, O. O. (2002). Management of major insect pests of rice in Tanzania. *Plant Protection Science* 38: 108 – 113.

Banwo, O. O., Makundi, R. H., Abdallah, R. H and Mbapila, J. C. (2001). Identification of vectors of *Rice Yellow Mottle virus* in Tanzania. *Plant Protection Science* 33: 395 – 403.

Burkill, H. M. (1995). *The Useful plants of West Tropical Africa, J-L, vol. 3*. Royal Botanic Garden, Kew, Great Britain pp. 1400–1410.

Charudattan, R. M., Coll, G. E., Heimpel, M. S., Hunter, H. K., Kay, J. W., Kiloepper, D., Beest, J. D., Van, D and Wackers, F. (2006). Biological control.http:// www.elsevier.com/wps/journaldescription.cws_home/622791/description#description] site visited on 06/07/2018.

Dale, D. (1994). *Biochemical aspects of varietal resistance to stem borer, Chilo suppressalis* (Walker). Final report. The International Rice Research Institute (IRRI) Los Banos, Philippines. 33pp.

Degri, M. M., Mailafiya, D. M and Mshelia, J. S. (2014). Effect of intercropping pattern on stem borer infestation in pearl millet (*Pennisetum glaucum* L.) grown in the Nigerian Sudan Savannah. *Advances in Entomology* 2: 81- 86.

Dent, D. (1991). *Insect pest management*. CAB International. Willingford, OX 10 8 DE. UK. 604pp.

FAO, (2015). *The rice value chain in Tanzania*. A report from the Southern Highlands Food Systems Programme. [www.fao.org/fileadmin/user_ upload/ivc/PDF/ SFVC/Tanzania_rice.pd] site visited on 11/05/2017.

Faria, M and Wraight, S. P. (2001). Biological control of *Bemisia tabaci* with fungi. *Crop Protection* 20: 767 - 778.

Fukon, M., Sarma, M. I., Borgohain, R., Sarma, B and Gowami, J. (2014). Efficacy of *Metarhizium anisopliae, Beauveria bassiana* and neem oil against tomato fruit borer, *Helicoverpa armigera* Hubner under field condition. *Asian Journal of Biological Science* 9(2): 151 - 155.

Funderburk, J., Higley, L and Buntin, G. O. (1993). Concepts and direction in arthropod pest management. *Advances in Agronomy* 5: 125 - 172.

Hailu, T., Selvaraj, T., Mengistu, L and Negery, M. (2012). Evaluation of some native entomopathogenic fungi against pink stem borer (*Sesamia calamistis* Hampson) (Lepidoptera: Noctuidae) in sugarcane. *Pest Management Journal of Ethiopia* 7: 1 - 9.

Huang, S., Wang, L., Liu, L., Fu, Q and Zhu, D. (2014). Nonchemical pest control in China rice: *A review of Agronomic Sustainable Development* 34: 275 – 291.

January, B., Rwegasira, G. M and Tefera, T. (2018a). Farmers' perceptions of rice production constraints and stem borers management practices in Tanzania. *Journal of Agricultural Science* 10(6): 57.

January, B., Rwegasira, G. M and Tefera, T. (2018b). Efficacy of selected biopesticides and botanical extracts in managing rice stem borer, Chilo partellus (swinhoe) lepidoptera: Crambidae) in Tanzania. *Journal of Agriculture and Ecology Research International* 15(4): 1 – 16.

Kanyeka, Z. L., Sangu, E., Fargette, D., Pinel-Galz, A and Herbrard, E. (2007). Diversity of local strains of rice yellow mottle virus in Tanzania. *African Crop Science Journal* 15(4): 201- 209.

Kibanda, N. J. M (2008). Rice research and production in Tanzania. Paper presented at the African Japanese plenary workshop on sustainable rice production held in Alexandria, Egypt on 23-25th August, 2008.

Lasisi, A. A and Adesomoju, A. (2015). Neoraudiol, a new isoflavonoid and other antimicrobial constituents from the tuberous root of *Neorautanenia mitis* (A. Rich) Verdcourt. *Journal of Saudi Chemical Society* 19 (4): 404-409.

Leonard, A. (2015). Incidences and spatial distribution of stem borers in rice crop in Kahama District. A Dissertation for Award of Msc. Degree at Sokoine university of Agriculture, Morogoro, Tanzania. 66pp.

Leonard, A., Rwegasira, G. M. (2015). Abundance and spatial dispersion of rice stem borer species in Kahama, Tanzania. *Jornal of Insect Science* 15 (1): 132.

Leticia, J., Mariam, A and Manuel, M. (2008). Pterocarpans: interesting natural products with antifungal activity and other biological properties. *Phytochemicals Revew* 7: 125–154.

MAFSC, (2009). National rice development strategy of the United Republic of Tanzania. Ministry of Agriculture, Food Security and Cooperative. [http:// www. kilimo.go.tz] site visited on 24/02/2017.

Mailafiya, D. M., Le Ru, B. P., Kairu, E. W., Calatayud, P. A and Dupas, S. (2009). Species diversity of lepidopteran stem borer parasitoids in cultivated and natural habitats in Kenya. *Journal of Applied Entomology* 133: 416 - 429.

Mailafiya, D. M., Le Ru, B. P., Kairu, E.W., Calatayud, P. A., Dupas, S. (2010). Factors affecting stem borer parasitoid species diversity and parasitism in cultivated and natural habitats. *Environmental Entomology* 39: 57 - 67.

Manisegaran, S, Lakshmi, S. M and Srimohanapriya, V. (2011). Field evaluation of *Metarhizium anisopliae* (Metschnikoff) Sorokin against *Holotrichia serrata* (Blanch) in sugarcane. *Journal of Biopesticides* 4(2): 190 - 193.

Materu, C. L., Shao, E. A., Losujaki, E., Chidege, M and Mwambela, N. (2015). Farmer's perception, knowledge and practices on management of *Tuta Absoluta* Meyerick (Lepidotera Gelechiidae) in tomato growing areas in Tanzania. *International Journal of Research Agriculture and Forestry 3*(2): 1 - 5.

Mghase, J., Shiwachi, H., Nakasone, K and Takahashi, H. (2010). Agronomic and socio-economic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research* 5: 150 - 158.

Moche, K., Lordon, C. D., Tadu, Z., Mokam, D. G., Nana, P. A., Fokam, Z and Woin, N. (2015). Diversity and agronomic impact of rice stem borer at Nkolbisson, Yaoundé-Cameroon (Central Africa). *International Journal of Agronomy and Agricultural Research* 6 (4): 181-189.

Mulungu, L. S., Luwondo, E. N., Reuben, S. O. W. M and Misangu, R. N. (2007) Effectiveness of local botanicals as protectants of stored beans (*Phaceolus vulgaris* L) agaist Bean bruchid (*Zabrotes subfaciatus* Boh). *Journal of Entomology* (4): 210 - 217).

Mulungu, L. S., Ndilahomba B., Nyange C. J., Mwatawala M. W., Mwalilino, J. K. Joseph, C. C and Mgina, C. A. (2011). Efficiency of *Chrrysanthemum cinerariaefolium*, *Neorautanenia mitis* and *Gnidia kraussiana* against larger grain borer (*Prostephanus truncates* Horn) and maize weevil (*Sitophilus zea mays* L.) grain seeds. *Journal of Entomology* 8: 81 – 87.

Muro, L. C. (2010). Efficacy of locally formulated baits in managing the melon fly *Bactrocera cucurbitae* (Coquilet) (Diptrrs: Tefritidae). A Dissertation Submitted in partial fulfilment of the requirements for the degree of Master of Science in Crop Science, Sokoine university of Agriculture, Morogoro. 56pp.

Niyibigira, E. I., Abdallah, Z. S., Overholt, W. A., Lada, V. Y and Van Huis, A. (2001). Distribution and Abundance of lepidopteran stem borers and associated indigenous parasitoids in maize and Sorghum in Zanzibar. *Insect Science Application* 21(4): 335 – 346.

Noorhosseini, S. A., Allahyari, M. S and Sabouri, M. S. (2010). Factors influencing the adoption of biological control of rice stem borer (*Chilo Suppressalis*) in Talesh Region, Iran. *International Journal of Agricultural Science and Research* 1: 1.

Nwilene, F. E., Sanyang, S., Taroe, A.K., Tagola, A., George, G. and Agunbbiade, T.A. (2008). *Rice stem borers: Biology, ecology and control*. Field guide and technical manual. Africa Rice Centre (WARDA)., Cotonou, Benin. 28pp.

Nyeko, P and Alubayo, F. M. (2005). *Participatory assessment of farmers' experience of termite problem in agroforestry on Tororo district, Uganda.* News Letter No. 143. Agricultural research and extension network. 18pp.

Oben, E. O., Ntonifor, N. N., Kekeunou, S and Abbevtakor, N. M. (2015). Farmers' knowledge and perception on maize stem borers and their indigenous control methods in south western region of Cameroon. *Journal of Ethnobiology and Ethnomedicine* 11: 77.

Oerke, E. C., Dehne, H. W. (2004). Safe guarding production losses in major crops and the role of crop protection. *Crop Protection* 23: 275 - 285.

Ogah, E. O. (2013). Field evaluation of plant extracts in the management of *Megalurothrips sjostedti* and *Maruca vitrata* of cowpea in Southeastern Nigeria. *World Essays Journal* 1: 11 - 17.

Ogah, E. O., Echezona, B. C and Umeh, E. D. N. (2005). Effects of nitrogen fertilization and spacing on African rice gall midge, *Orseolia oryzivora* Harris and Gagné in a Sub-humid area of Southern Nigeria. *Journal of Agriculture, Food, Environment and Extension* 4(2): 15 - 18.

Ogah, E. O., Omoloye, A. A., Nwilene, F. E., Nwogbaga, A. C. (2011). Effect of Neem seed kernel extracts in the management of rice stem borers in the field in Nigeria. *Journal of Biotechnology* 23:13 - 21.

Parmar, B.S., Walia, S., Koul, Oand Dhaliwal, G. S. (2001). Prospects and problems of phytochemical biopesticides. *Phytochemical Biopesticides* 9:192-223.

Pathak, M and Khan, Z. R. (1994). *Insect pests of rice*. International centre of insect physiology and ecology (icipe), International rice research institute, Manila Philippines. 5 – 16pp.

Pathak, M. D. (1968). Ecology of rice pests. *Annual Revew of Entomology* 13: 257 – 294.

Polaszek, A. (1998). African cereals stem borers: Economic importance, taxonomy, natural enemies and control. Wallingford, UK, CABI. 530pp.

Prasad, S. S and Gupta, A. K. (2012). Compatibility of new insecticides and fungicides against stem borer and leaf blast on semi-deep water rice. *Crop Research* 43(3): 197 - 200.

Rami, K., Overholt, W. A., Khan, Z. R and Polaszek, A. (2002). Biology and management of economically important lepidopteran cereal stem borers in Africa. *Annual Review of Entomology* 47: 701 – 31.

Sangmaneedet, S., Kanistanon, K., Papiron, P and Tessir, T. (2005). Uses of Thai medicinal herb (*Derris eliptica* (Roxb.) Benth) in Control of fly larva population and its application in the treatment of cutaneous myiasis in animals. *K.KU Research Journal* 10(1): 22 - 36.

Sarwar, M. (2011). Effects of Zinc fertilizer application on the incidence of rice stem borers (*Scirpophaga*species) (Lepidoptera: Pyralidae) in rice (*Oryza sativa* L.) crop. *Journal of Cereals and Oilseeds* 2(5): 61 - 65.

SASA. (1994). Eldana borer control measures. Experiment station information sheet: SASA. Mount Edgecombe, Natal: *South Africa Sugar Association*. 42pp.

Shahid, A. A., Rao, A. Q., Bakhsh, A., Husnain, T. (2016). Entomopathogenic fungi as biological controllers: New insights into their virulence and pathogenicity. *Achieves of Biological Science Belgrade* 64 (1): 21 - 42.

Suraphon, V. and Manthana, M. (2001). Effects of roots extracts from Derris (Derris elliptica Benth) on mortality and detoxicification enyzme levels in the Diamondback Moth Larvae (Plutella xylostella Linn.). *Journal of Natural Science* 35: 157-163.

Su, J., Xuan, W., Sheng, C. and Feng, G. E. (2003). Suppression of rice stem borer, *Chilo suppressalis* by mass trapping using synthetic sex pheromones in paddy field. *Journal of Rice Science* 11: 52 - 56.

Tefera T. (2004). Farmers' perceptions of sorghum stem-borer and farm management practices in Eastern Ethiopia. *International Journal of Pest Management* 50 (1): 35 - 40.

Teshome, A and Tefera, T. (2009). Susceptibility of *Sitophilus zeamais* (Mostch.) (Coleoptera: Curculionidae) to *Beauveria bassiana* and *Metarhizium anisopliae*. *Ethiopia Journal of Science* 32(1): 21 - 28.

Togola, A., Boukar, O., Tamo, M and Chamarthi, S. (2020). Stem borers of cereal crops in Africa and their management, pests control and acarology. *Dalila Haouas and Levente Hufnagel, IntechOpen 10: 57 – 72.*

UNDP, (2010). Rice cultivation in Thailand: Sustainable rice production system scoping paper. *Green commodity facility* 12: 7 - 8.

United Republic of Tanzania, (2013). *Population and Housing Census of 2012*. National Bureau of Statistics, Ministry of Finance Dar es Salaam. 244pp.

Visetson, S and Milne, M. (2001). Effects of root extract from Derris (*Derris elliptica* Benth) on mortality and detoxification enzyme levels in the Diamond back moth larvae (*Plutella xylostella* Linn.). *Kasetsart Journal of Natural Science* 35: 157 - 163.

Wale, M., Schulthess, F., Kairu, E and Omwega, C. O. (2006). Cereal yield losses caused by lepidopterous stemborers at different nitrogen fertilizer rates in Ethiopia. *Journal of Applied Entomology* 130(4): 220 – 229.

Zubairi, S. I., Sarmidi, M. R and Aziz, R. A. (2014). A Study of Rotenone from Derris roots of varies location, plant parts and types of solvent used. *Advanced Environtal Biology* 8(2), 445-449.

CHAPTER TWO

2.0 FARMERS' PERCEPTIONS OF RICE PRODUCTION CONSTRAINTS AND STEM BORERS MANAGEMENT PRACTICES IN TANZANIA

Published in *Journal of Agricultural Science*; 10 (6): 57 - 71. doi:10.5539/jas.v10n6p57

Abstract

Rice farmers in Tanzania continue to experience losses due to stem borers. However, the information on farmers' knowledge and perceptions of rice stem borers is limited and farmers' efforts on managing this insect have been ineffective. The aim of this study was to investigate constraints affecting rice production and farmers' approaches of stem borer management in irrigated low land rice ecosystems in Tanzania. Data were collected using a structured questionnaire through face to face interview with farmers. The information collected included: farmers' socio-economic profiles, farm characteristics, knowledge and perceptions of stem borers and their management practices. About 96.76 % of farmers reported insect pests such as stem borers, white flies, leaf rollers and grasshoppers as major constraints of rice production. Other constraints reported were such as diseases, damage by birds, drought, weeds and lack of access to credit for purchasing inputs. Most of the farmers (78.2%) apply chemical insecticides against rice insect pests particularly stem-borers where number of health hazards have been reported. Very few farmers (18.5%) use cultural methods including crop residue disposal and split application of nitrogenous fertilizers for reduction of stem borer damages. The study revealed that, most farmers have limited knowledge on the recommended stem borer management practices and suggests that environmentally friendly pest management methods to be designed and implemented to minimize losses associated with rice stem borers.

Keywords: Farmers' perceptions, constraints, low land rice, management practices, stem borers, Tanzania

2.1 Introduction

Rice (*Oryza sativa* L.) is the dominant staple food in the developing world (Sarwar, 2012). Rice comes next to maize as most cereal food crop in Tanzania and it is grown in more than 10 regions (Mghase *et al*., 2010). However the yield is very low, 1 - 1.5 tons per hactre compared to potential yield of six to ten tones per hectare (Ngailo, 2016) due to several constraints including insect pests (RLD, 2009). More than one hundred species of insects have been reported to attack rice crop among which are rice stem borers (Pathak, 1968). An estimated rice yield loss of about 10% is incurred by rice insect pests to resource-poor farmers in developing countries (Mati, 2009) and rice grain yield loss of up to 91% due to stem borers have been reported in Kenya (Kega *et al*., 2016).

Rice stem borers have been reported as the most economically important insect pests of rice (Sigsgaard, 2000). There are about 20 stem borer species which have been reported worldwide as insect pests of rice with only four species reported in Africa as pests of economic importance. These include: Spotted stem borers (*Chilo* spp.), Stalk eyed fly (*Diopsis longcornis* Macquart), African white stem borer (*Maliarpha separatalla* Ragonot) and African Pink stem borer (*Sesamia calamistis* Hampson) (Ogah, 2013). Rice stem borer species in East Africa belongs to two orders namely, Diptera and Lepidoptera. The Dipteran stem borers include only one species named *D. thoracica* whereas Lepidopteron stem borers include three main species; *M. separatella*, *S. calamistis* and *Chilo partellus* Swinhoe (Srivastava *et al*., 2003). On average the stem borer species eggs lasts for 15 days, larval stage for 40 days, and pupa for 11 days and adults live for two to six days (Nwilene *et al*., 2008). In Tanzania, three lepidopteran stem borers have been reported as pest of economic importance in rice which includes *C. partellus*, *M. separatella* and *S. calamistis* (Banwo *et al*., 2002; Leornard and Rwegasira, 2015).

Management of stem borers is a bioeconomical selection of management tactics by considering several factors such as economics, ecology and social factors (Korir *et al.*, 2016). Understanding farmers' perception of stem borer problem and management tactics prior to engaging in to any research on managing the pest was imperative. Engaging farmers at planning stage of research is important in ensuring the relevance of any research to them. For example, Farrington and Martin (2005) reported that, involvement of farmers in research studies increases the chances of success in generation of appropriate agricultural technology. Studies by (Witcombe *et al.*, 2015; Sheikh *et al.*, 2017) reported participatory plant breeding were shown to be an effective way of selecting locally adapted rice genotypes and for improving farmers' access to useful crop genetic diversity in Rwanda.

Farmer's perception and indigenous knowledge on pests' management have been reported to provide useful information to incorporate into scientific knowledge for management of pests of economic importance (Grace, 1990; Bentley and Thiele, 1999). For example, Nyeko and Alubayo (2005) reported on termite management in Uganda, Tefera (2004) on sorghum stem borer management in Ethiopia, Oben *et al.* (2015) on maize stem borer's management in Cameroon, Gadisa and Birhane (2015) on Rodents control in Ethiopia and Materu *et al.* (2016) reported on management of tomato leaf miner (*Tuta absoluta* Meyerick) in Tanzania.

Rice farmers in Tanzania continue to experience losses due to stem borers. However, the information on farmers' knowledge and perceptions of rice stem borers is limited and farmers' efforts on managing this insect have been ineffective. Understanding farmers' socio-economic factors, their knowledge, perceptions, and their current pest management practices are critical steps towards developing sustainable and cost effective integrated pest management (IPM) strategies (Alibu *et al.*, 2016). The aim of this study was to determine farmers' perceptions of rice production constraints and stem borer's management practices in irrigated lowland rice ecosystems in Tanzania.

2.2 Materials and Methods

2.2.1 Description of the study sites

Field surveys were conducted in three wards in Kilombero valley of Kilombero district, Morogoro Tanzania which are under irrigated rice ecosystem from December 2016 to January 2017. A total of six villages, two from each ward, were surveyed (Fig. 2.1). The six villages covered by the study were Signali (7°59′54.1115″ S, 36°50′7.0177″ E, 271 m.a.s.l) and Sululu (7°59′45.8149″ S, 36°50′7.7237″ E, 268.81 m.a.s.l) in Signal ward; Mkula (7°46′4.2672″ S, 36°56′43.4076″ E, 261.27 m.a.s.l) and Msufini (7°47′30.125″ S, 36°54′7.9283″ E, 283.98 m.a.s.l) in Mkula ward and Sanje (7°45′33.1981″ S; 36°55′15.0247″ E, 307.788 m.a.s.l) and Msolwa (7°45′58.729″ S, 36°54′58.9878″ E, 289.03 m.a.s.l) in Sanje ward.

These wards represent irrigated low land rice ecosystem of Tanzania, where rice cultivation is constrained by rice stem borers. The three wards have total number of 942 household farms of rice which are under irrigation including, Signali (220), Mkula (294) and Sanje (428) (Mosha *et al.*, 2016). Most villages in the district experience bimodal rainfall pattern characterized by two rainfall peaks in a year with a definite dry season separating the short and long rains. The short rain season is from October to December while the long rain season starts from March and ends in May (Msanya *et al.*, 2003). Despite the bimodal occurrence of rains, rice is continuously grown under irrigation systems.

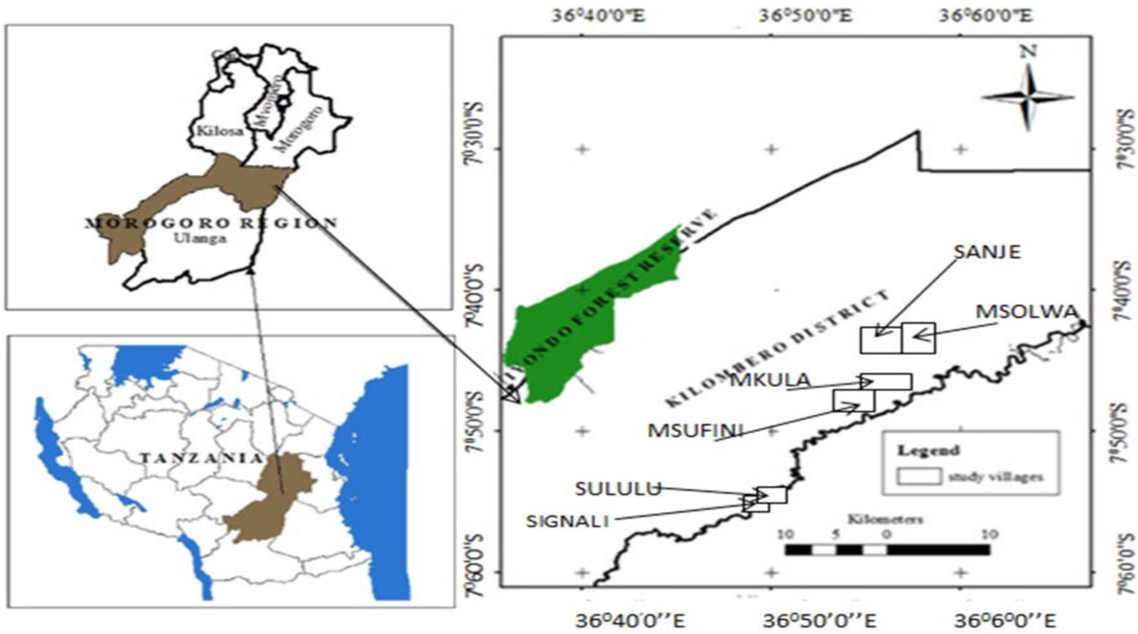


Figure 2.1: Map of Tanzania showing the six studied villages in Kilombero district

The study villages are indicated by arrows.

2.2.2 Sampling procedure

Multi-stage and cluster-sampling techniques were used to identify the village samples to ensure good representativeness of rice farming population in the study areas. In the first stage, three wards namely; Sanje, Mkula and Signal were identified as among the key irrigated low land rice ecosystem in Kilombero Tanzania; thus, targeted for the study. At the ward level, two respective villages from each ward were purposively selected for sample household's survey. The villages were Sanje and Msolwa of Sanje ward, Mkula and Msufini of Mkula ward and Signal and Sululu of Signali ward. In each village 10 farmers were selected for face to face interview. The three wards and the two villages in Kilombero district were selected because of their intensive rice cultivation due to availability of enough water for irrigation throughout the year. The sample size (N) was determined by using Equation as described by Wonnacott and Wonnacott (1990) attest as follows:

$$N = \frac{Z^2 P(1-p)}{\Phi^2} \text{ ……………………………………………………………….. (i)}$$

Where, N = required sample size, Z = confidence level at 95% (standard value of 1.96), p = estimated proportion of an attribute, which was estimated at 90% (standard value of 0.9) due to the fact that about 90% of the rural population in Tanzania are employed in farming activities (Mlambiti, 1998) and Φ = margin of error at 5% (standard value of 0.05). Therefore, using Equation above N was determined.

$$N = \frac{Z^2 P(1-p)}{\Phi^2} = \frac{Z(1.96)^2(0.9)(1-0.9)=138.297\approx 140}{(0.05)^2} \text{ ……………………..……... (ii)}$$

The sample size of 138.3, approximated to 140 households was equally distributed between Sanje, Msolwa, Mkula, Msufini, Signali and Sululu villages accounting for twenty-four (24) farming households in each village. Due to time constraint and poor road network, a target of twenty (20) households (representing 83.33% of village sampled population) was expected to participate in the formal interview. Ultimately, 10 respondents from each village making a total of sixty (60) households were recorded (representing a response rate of 41.67%) which was satisfactory for this study. This number was in line with the study of Saunders *et al*. (2007) who argued that a sample size of 30 or more will result into sampling distribution which is very closer to the normal distribution. The selection of farmers was done in collaboration with village leaders and agricultural extension officers taking into consideration the gender, age of farmer, education, farm size and income.

2.2.3 Data collection

A structured questionnaire (Appendix 1) was administrated by trained agricultural enumerators after pre-testing the questionnaire for its validity. The information collected included: farmers' socio-economic profiles, farm characteristics, knowledge and perceptions of stem borers and their management practices. Farmers were interviewed in their local language (Kiswahili) at their home for 40 - 45 min. The questionnaires were discussed during face to face interviews with individual farmers and addressed information on farmers' socio-economic profile (e.g. age, gender, education, and family size), farm size and rice production constraints.

2.2.4 Data analysis

Quantitative and qualitative data collected through the questionnaire were coded and subjected to statistical analyses using the Statistical Package for Social Sciences software (SPSS Inc., 2016). Cross-tabulations tables were constructed and descriptive statistics were calculated to summarize data from the questionnaires. To make statistical inferences, contingency chi-square tests were computed at a given level of significance to analyze relationships between variables. This allowed empirical analyses and description of associations between the collected parameters across the six study villages.

2.3 Results

2.3.1 Basic information of the households

Rice farming system under study area is represented by smallholder farmers with an average land size ranging from less than 1 - 3 acres with very few farmers owning more than 3 acres (Table 2.1). The proportion of male-headed households was higher than females-headed. About 61.7% of the farmers interviewed were aged between 18 - 45 years, a suitable and energized age group for field work. The remaining 38.3% were for old age group. About 50% of the respondents had family size of four to six individuals. Most farmers were gone to school to at least primary level and able to read and write in National language (Kiswahili), with very few (6.7%) who were illiterate and unable to read and write. About 70% the farmer's income was through rice farming with an average grain yield of 4949.38 Kg ha^{-1} (Table 2.1) whilst 71.6% of the yield was used for home consumption and 28.3% was sold (Fig. 2.2).

Table 2.1: Respondents' demographic and social economic parameters in study sites

Variable	Class	Percentage contribution of parameters in each village						Mean
		Sululu	Signali	Mkula	Msufini	Sanje	Msolwa	
Gender	Male	80	40	60	60	80	50	61.7
	Female	20	60	40	40	20	50	38.3
Age (years)	18-35	20	30	50	30	20	10	26.7
	36-45	40	40	40	40	30	20	35.0
	46-60	30	30	10	30	30	40	28.3
	61-80	10	0	0	0	20	30	10.0
Family size	≤ 3	40	10	50	0	10	30	23.3
	4-6	60	60	30	60	50	40	50.0
	7-10	0	20	20	40	20	20	20.0
	> 10	0	10	0	0	20	10	6.7
Education level	Primary	90	10	90	90	70	80	71.7
	Secondary	10	90	10	10	10	0	21.7
	Illiterate	0	0	0	0	20	20	6.7
Size of rice field (acres)	≤ 1	10	0	30	20	30	20	18.3
	2-3	90	100	70	70	70	60	76.7
	> 3	0	0	0	10	0	20	5.0
Proportion of farmer 'income which is from rice	< 0.5	50	20	10	10	30	60	30.0
	> 0.5	50	80	90	90	70	40	70.0
Yield (Kg/ha) in 2016		4388	5873	3709	6120	6023	3585	4949

Number of respondents (N) = 60.

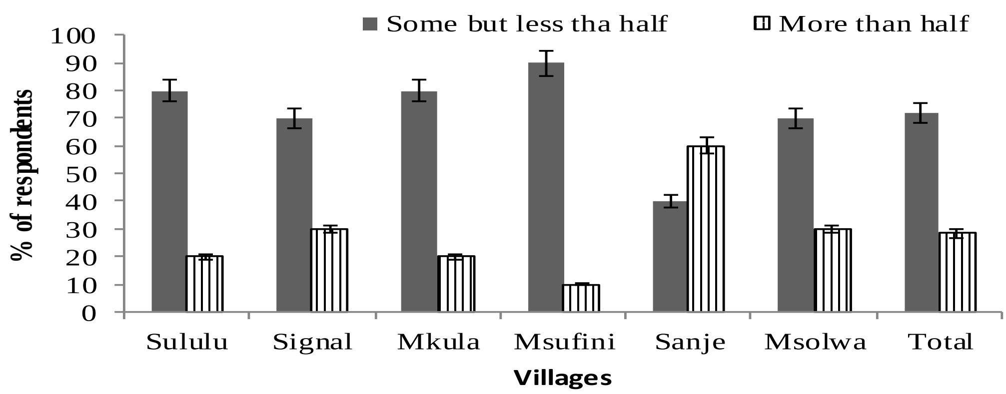


Figure 2.2: Proportion rice yield used for home consumption

2.3.2 Farmers' awareness on rice stem borers

During survey both male and women farmers were asked whether they know rice stem borers. The results indicated that more than 92% of interviewed farmers were aware of stem borer problem leaving out only 8% who were not aware. The influence of sex on awareness of rice stem borers problem was not significantly different among men and women (χ^2= 0.06; *P* = 0.936) (Table 2.2). Both men and women were equally aware on stem borer problem.

Table 2.2: Farmers awareness on rice stem borers

Sex of respondent	**Aware**	**Unaware**	**Total**	**Chi-square**	**df**	***P*-value**
Women	21(35)	2 (3)	23(38)	0.06	1	0.936
Men	34 (57)	3 (5)	37(62)			
Total	55(92)	5 (8)	60(100)			

df = degrees of freedom; number of respondents (N = 60); numbers in brackets presents the percentage contribution of the respective paramers

2.3.3 Rice stem borer management practices

The relationship between different age groups and education level of respondents and stem borer management options are presented in Table 2.3. Most farmers reported to use insecticides in management of rice stem borers regardless of age or education levels. Very few farmers reported to use cultural practiced such as burning of crop residues, remove and burry infested plants and split application of nitrogen fertilizer. Stem borer management options were neither influenced by the age groups (X^2 = 8.85; *P* = 0.715) nor education levels (χ^2 = 12.99; *P* = 0.112).

Table 2.3: Relationship between farmers age and education level with rice stem borer management practices

Variable	Class	Stem borer management options								
		Burning of crop residues	Remove and burry infested plants	Use of insecticides	Split application of Nitrogen fertiliser	Not using any management option	Total	Chi-square	df	*P*-value
Age (years)	18-35	3(5)	1(1.67)	11(18.35)	0(0)	1(1.67)	16(27)	8.85	12	0.715
	36-45	4(6.7)	0(0)	15(25)	1(1.67)	1(1.67)	21(35)			
	46-60	0(0)	1(1.67)	16(26.6)	0(0)	0(0)	17(28)			
	61-80	1(1.67)	0(0)	5(8.33)	0(0)	0(0)	6(10)			
	Total	8(13.37)	2(3.34)	47(78.28)	1(1.67)	2(3.34)	60(100)			
Education level	Primary	0(0)	1(1.7)	2(3.3)	0(0)	0(0)	3(5)	12.99	8	0.112
	Secondary	7(11.7)	1(1.7)	41(68.3)	1(1.7)	1(1.7)	51(85)			
	Illitrates	1(1.7)	0(0)	4(6.6)	0(0)	1(1.7)	6(10)			
	Total	8(13.3)	2(3.3)	47(78.3)	1(1.7)	2(3.3)	60(100)			

df = degrees of freedom; number of respondents (N = 60); numbers in brackets presents the percentage contribution of the respective parameters

2.3.4 Constraints to rice production

Most farmers, 96.76%, reported insect pests such as stem borers, white flies, leaf rollers and grasshoppers as major constraints to rice production (Fig. 2.3). Other constraints reported were such as diseases, damage by birds, drought, weeds and lack of access to loan for purchasing inputs such as improved seeds, fertilizers, insecticides and herbicides. Of all production constraints, birds and insect pests were mentioned as most constrained by farmers whereas drought was ranked as least constraint. The production constrains by farmers did not differed significantly among the villages except for weeds, diseases and drought (*P* = 0.093).

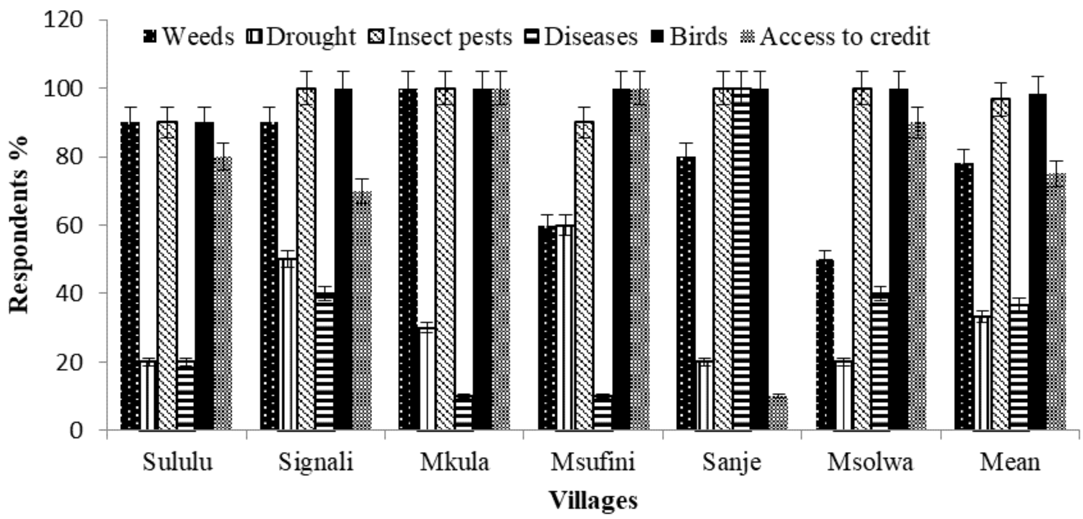


Figure 2.3: Farmers' perception on rice production constraints

2.3.5 Farmers' perception on infestation with rice stem borers

Most farmers reported stem borers as most serious insect followed by white flies, leaf rollers and grasshoppers (Fig. 2.4). Among the farmers interviewed, less than 50% of the respondents reported the stem borer infestations levels were high during previous year whereas more than 50% reported the infestation levels were medium to low. There was no significant differences between stem borer infestation levels within villages (χ^2 = 14.8; *P* = 0.141) (Table 2.4).

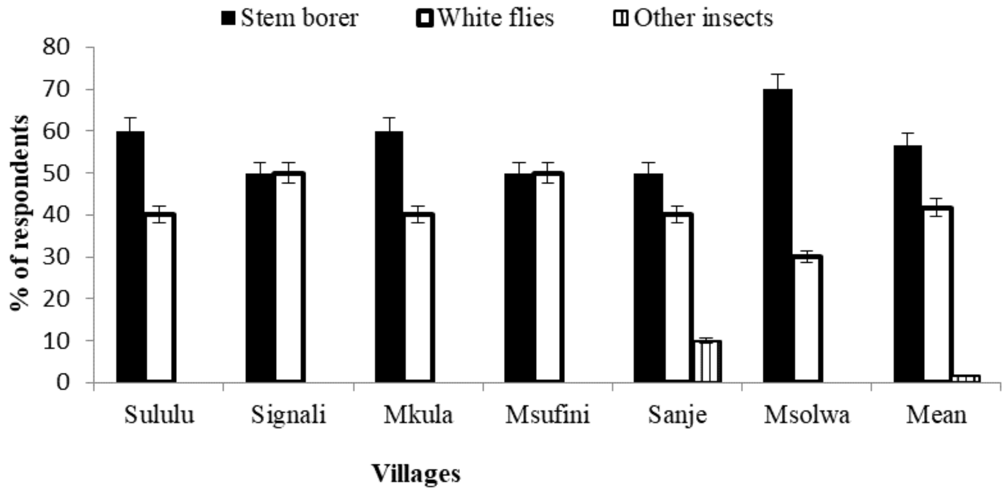


Figure 2.4: Most important rice insect pests which infests rice

Table 2.4: Farmers' perception on rice stems borers' infestation

Stem borer Infestation level	**Wards**						**Mean**	**Chi-square**	**df**	***P*-value**
	Signali		**Mkula**		**Sanje**					
	Sululu	**Signali**	**Mkula**	**Msufini**	**Sanje**	**Msolwa**				
Low	0(0)	0 (00)	6 (10)	0 (0)	0 (0)	12 (20)	3 (5)	14.8	10	0.14
Medium	48 (80)	48 (80)	24 (40)	36 (60)	24 (40)	18 (30)	33 (55)			
High	12 (20)	12 (20)	30 (50)	24 (40)	36 (60)	30 (50)	24 (40)			

df = degrees of freedom; number of respondents (N = 60); numbers in brackets presents the percentage contribution of the respective paramers

2.3.6 Inputs used by rice farmers for management of stem borers

The insecticides used by rice farmers were Kung'fu, Karate and Atakan which are having the same active ingredient called lambda cyhalothrin (Table 2.5). More than 50% of farmers reported to use this chemical insecticide in stem borer control with very few (< 50%) that were not using insecticide. Several fertilizers such as UREA, Di-ammonium phosphate (DAP) and Minjingu phosphate were reported to be used by farmers where by Nitrogenous fertilizer such as UREA and DAP were used by most farmers (> 90%). Very few farmers (< 10% of respondents) were not using any fertilizer (Table 2.5).

2.3.7 Rice growing season and stem borer's damage

Most farmers reported that stem borers infestations were more severe during dry season than wet season with very few (< 20%) of the respondents who reported that infestations were equally severe in both two seasons. There was no significant difference ($\chi^2 = 8.5$; $P = 0.902$) in stem borer infestations among villages for both wet and dry season (Table 2.6).

Table 2. 5: Inputs used by farmers

Inputs used	Input type	Villages of respondents						Mean
		Sululu	Signali	Mkula	Msufini	Sanje	Msolwa	
Insecticides	Kung'fu	12 (20)	18 (30)	12 (20)	6 (10)	24 (40)	24 (40)	16 (26.7)
	Karate	30 (50)	12 (20)	12 (20)	6 (10)	12 (20)	18 (30)	15 (25.0)
	Amekan	6 (10)	18 (30)	18 (30)	6 (10)	6 (10)	6 (10)	10 (16.7)
	Not using any insecticide	12 (20)	12 (20)	18 (30)	42 (70)	18 (30)	12 (20)	19 (31.6)
Fertilizers	Using Urea	0 (0)	0 (0)	18 (30)	6 (10)	12 (20)	0 (0)	6 (10.0)
	Using DAP	12 (20)	0 (0)	6 (10)	18 (30)	0 (0)	0 (0)	6 (10.0)
	Using DAP and Urea	30 (50)	100 (60)	36 (60)	30 (50)	12 (20)	36 (60)	34 (56.7)
	Using Urea and Minjingu phosphate	18 (30)	0 (0)	0 (0)	0 (0)	30 (50)	24 (40)	12 (20.0)
	Not using any fertilizer	0 (0)	0 (0)	0 (0)	6 (10)	6 (10)	0 (0)	2 (3.3)

DAP = Di-Ammonium Phosphate; Number of respondents (N= 60); df = degrees of freedom; Number of respondents (N = 60); numbers in brackets presents the percentage contribution of the respective paramers

Table 2.6: Stem borer infestation based on cropping season

Season	**Wards**						**Mean**	**Chi-square**	**df**	***P* - value**
	Signali		**Mkula**		**Sanje**					
	Sululu	**Signali**	**Mkula**	**Msufini**	**Sanje**	**Msolwa**				
Wet season	12(20)	6(10)	18 (30)	12 (20)	18 (30)	6 (10)	12 (20)	8.5	15	0.902
Dry season	24 (40)	18 (30)	24 (40)	24 (40)	24 (40)	30 (50)	24 (40)			
Both wet and dry season	6 (10)	18 (30)	12 (20)	6 (10)	6 (10)	0 (0)	8 (13)			
Not known	18 (30)	18 (30)	6 (10)	18 (30)	12 (20)	24 (40)	16 (27)			

df = degrees of freedom; Number of respondents (N = 60); numbers in brackets presents the percentage contribution of the respective paramers

2.4 Discussion

Rice cultivation in the study area was represented by small scale farmers the majority of whom were males with very small piece of land which are all under irrigation system. All individuals interviewed were older than 18 years which is essential group for decision making power on the crop and variety to grow, the size of land to cultivate and the date of planting, which in turn have an impact in rice production (Mrema *et al*., 2015). Most farmers under the study area have either attended primary school or illiterate with very few who attended secondary schools to form four levels. This suggests that service providers must communicate orally during services. The few educated individual farmers could act as facilitators alleviating constraints and identifying needs and priorities of none educated farmers and enhance adoption of any new technologies of rice cultivation in the study area.

Most farmers could not delineate whether rice production constraints existed or not. Lack to clear separation between the existence and non-existence of production constraints was attributed to similarity in soil characteristics, rainfall distribution, cropping system and pest management practices of the farmers under the study area. All these factors influence insect pests' infestation to the rice crop. The influence of environmental conditions are in tandem with the observation by Hossain *et al*. (2013) who reported that the low yield of rice in Bangladesh was attributed to poor soil fertility status, rainfall distribution pattern, cropping system and management practices of insect pests. The importance of insect pests as the most significant production constraint in the study area is attributed to the availability of water throughout the year which prompt farmers to grow rice crop twice or thrice a year. Repeated growing rice favors survivorship and reproductions of insect pests particularly stem borers due to assurance of food supply throughout the life cycle from the host.

Most interviewed farmers indicated medium to high severity of insect pest infestation in the year 2016 with stem borers being the most severe insect among the insects mentioned. This is attributed to the fact that most of farmers under the Kilombero irrigation scheme are used to plant rice crop in common and fixed planting dates every season that may have influence in rice insect pest infestation. This concurs with the study of Sarwar (2012) who reported that planting dates showed impact on the incidence of stem borers by which early planted rice crop was the most resistant having the lowest borer infestation among other plantings. Further, Kfir *et al*. (2002) reported that crops grown at the period of least abundance of the pest ensures no interference between most susceptible stage of crop growth and the period of peak stem borer activity.

Stem borer management practices including use of insecticides, uprooting and burning of infested plants and split application of nitrogen fertilizer were reported to be used by farmers during the survey under the study area thereby insecticides being used by most of farmers. The stem borer management options were neither influenced by gender nor education level. This was because most of farmers were of the same and of low education level (primary education) with little knowledge on selection of best and proper pest management options. Management of insect pests using chemical insecticides particularly in rice crop are still effective method (Sigh *et al*., 2015) but indiscriminate use can result in disruption of environment by accumulating the residues to the harvested produce which are not safe to human health. The chemical insecticides can also affect non-target organisms such as natural enemies which are user friendly to farmers by reducing their numbers (Preetha *et al*., 2009; Sigh *et al*., 2015).

Several fertilizers such as UREA, DAP and Minjingu rock phosphate were reported by the respondents during survey as being used in rice crop for the purpose of increasing yield and/or reducing insect pest infestation. Nitrogenous fertilizer such as UREA and DAP has direct influence on the vigor and increase of the tenderness of rice crop (Mgoo *et al*., 2005). These in some ways promote damages by stem borers especially when not used properly. The effect of fertilizer inputs has also described by Sarwar (2011) who reported how important is the plant nutrient in changing population dynamics of herbivores apart from being a good indicator in improving host plant quality. This was further supported by the study by Ogah *et al.,* (2005) who reported increased rice gall midge damages in nitrogen applied plots as compared to the control.

During the survey, it was also indicated that stem borer’s infestation in previous year was more severe during dry season than wet season. Mgoo *et al.* (2005) reported high abundance of maize stem borers during short rain season than in long rain season. Kega *et al*. (2017) reported that pest densities were found to be high in off season than rain season planted rice due to repetition of rice cultivation that favours population build-up of vegetative rice pests. In addition, continuous cultivation of rice under irrigated lowland rice ecosystem could favor the abundance of diverse vegetation which acts as alternative host to pests. In line with the findings of the current study, Mailafiya *et al*. (2011) reported numerous wild host plants like *Cyperus* spp, *Panicum* spp, *Pennisetum* spp. and *Sorghum* spp. which are also found in the study area suggesting their potentiality as hosts of rice stem borers whenever is found. Continuation of stem borers breeding cycle may be another reason for high stem borer infestation reports during dry season than wet season in the study area. In contrary, during dry season stem borers tends to undergo resting period (diapause) due to insufficient food materials (Pathak and Khan, 1994). This usually happened only under rain fed ecosystem where the crop is cultivated only once per year, unlikely under the study area where the crop is cultivated twice or thrice ensures continuous breeding cycle due to availability of host plant for feeding hence more infestation.

Change of environmental conditions can also be the cause of high stem borer infestation during dry season as reported by farmers in the current study. This is supported by the report of Khaliq *et al*. (2014) that distribution, development, survival, behavior, migration, reproduction and population dynamics of insect pests of rice are affected by change of climatic factors such as temperature, relative humidity, rainfall and mass air movements. On the other hand, the high infestation of stem borers in dry season was contributed by continuous cultivation of rice under irrigation system that ensures continued availability of rice, the suitable host for the pest. Similar observation was reported by Hong-xing *et al*. (2017) who reported that intensive rice cultivation was the cause of increased stem borer's infestation levels.

2.5 Conclusion and recommendations

The present study unveils in depth knowledge of the farmers on rice production constraints whereby rice stem borer was identified as a major pest. The pest was omnipresent in all locations where rice is grown. Rice production in the study area is continuous which provides suitable environment for breeding and perpetuation of rice stem borers. There exists no effective management practices against the pest which are popular among farmers hence several methods are used which are ineffective. New innovations designed to control stem borers in rice under subsistence farming in Africa should consider farmers' knowledge of the pest, socio economic circumstances and current pest management practices.

Acknoledgements

This study was made possible through support provided by the Feed the Future Collaborative Research on Integrated Pest Management Innovation Lab of the US Agency for International Development, under the terms of grant No. AID-OAA-L-15-00001. The authors are grateful to the farmers and agriculture extension staff in Tanzania who participated in this study.

References

Alibu, S., Otim, M. H., Okello, S. E. A., Lamo, J., Ekobu, M and Asea, G. (2016). Farmers' knowledge and perceptions on rice insect pests and their management in Uganda. *Journal of Agriculture 6*(3): 38.

Banwo, O. O. (2002). Management of major insect pests of rice in Tanzania. *Plant Protection Science 38*: 108 - 113.

Bentley, J. W and Thiele, G. (1999). Farmer knowledge and management of crop disease. *Journal of Agriculture and Human Value 16*: 75 - 81.

Gadisa, T and Birhane, A. (2015). Farmers' perceptions of rodents as crop pests: Knowledge, attitude and practices of farmers about rodent pest nagement in Southwest Ethiopia. *Journal of Agricultural Extensionand Rural Development 8*(3): 39 - 46.

Grace, J. Y. (1990). Public perception of termite control practices in several Ontario (Canada) Municipalities. *Journal of Environmental Management 30*: 131-138.

Hong-xing, X., Ya-juna, Y., Yan-huia, L., Xu-songa, Z., Jun-cea, T., Feng-xiang, L., Zhong-xian, L. (2017). Sustainable management of rice insect pests by non-chemical-insecticide technologies in China. *Rice Science 24*: 61 - 72.

Hossain, M. K., Kamil, A. P., Masron, T. A and Baten, M. A. (2013). Impact of environmental factors on efficience of rice production in Bangladesh. *Journal of Applied Science 3*(4): 564 - 571.

Kega, V. M., Kasina, M., Olubayo, F and Nderitu, J. H. (2016). Assessment of yield loss caused by African White Rice Stem Borer (*Maliarpha separatella* Rag.) (Lepidoptera: Pyralidae) at Mwea Irrigation Scheme, Kirinyaga County, Kenya. *Journal of Entomology 13*: 19 - 25.

Kega, V. M., Kasina, M., Olubayo, F and Nderitu, J. H. (2017). A Study of the African white rice stem borer (*Maliarpha separatella* Rag.) population density fluctuations at Mwea Irrigation Scheme in Central Kenya. *Universal Journal of Agricultural Research 5*(1): 52 - 56.

Kfir, R., Overholt, W. A., Khan, Z. R and Polaszek, A. (2002). Biology and management of economically important lepidopteran cereal stem borers in Africa. *Annual Review of Entomology 47:* 701 - 731.

Khaliq, A., Javed, M., Sohail, M and Sagheer, M. (2014). Environmental effects on insects and their population dynamics. *Journal of Entomology and Zoology Studies 2*: 1 - 7.

Korir, J., Muricho, G and Kassie, M. (2016). *Farmers' Perceptions of maize stem borer and ddoption of integrated pest management practices in Nakuru and Bomet Counties, Kenya*. Rice, Maize and Chickpea IPM for East Africa Project. Working document series 4. 15pp. [https://ipmil.oired.vt.edu/ wp-content/10/ Maize_KAP-paper_12042017-final.pdf] site visited on 17/07/2017.

Leonard, A and Rwegasira, G. M. (2015). Abundance and spatial dispersion of rice stem borer species in Kahama, Tanzania. *Journal of Insect Science 15*(1): 132.

Mailafiya, D. M., Le Ru, B. P., Kairu, E. W., Dupas, S and Calatayud, P. A. (2011). Parasitism of lepidopterous stem borers in cultivated and natural habitats. *Journal of Insect Science* 11(15): 1 - 19.

Materu, C. L., Shao, E. A., Losujaki, E., Chidege, M and Mwambela, N. (2015). Farmers' perception, knowledge and practices on management of *Tuta Absoluta* Meyerick (Lepidotera Gelechiidae) in tomato growing areas in Tanzania. *International Journal of Research Agriculture and Forestry 3*(2): 1 - 5.

Mati, B. M. (2009). *System of rice intensification; growing more with less water promoting the adoption of SRI in Kenya*. IMAWESA brief notes. 6pp.

Mghase, J., Shiwachi, H., Nakasone, K and Takahashi, H. (2010). Agronomic and socio-economic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research 5*(2): 150 - 158.

Mgoo, V. H., Makundi, R. H., Pallangyo, B., Schulthess, F., Jiang, N and Omwega, C. (2006). Yield loss due to the stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) at different nitrogen application rates to maize. *Annals Society Entomology of France 42*: 3 - 4.

Mlambiti, M. E. (1998). *Introduction to Rural Economy for East African Students*. Mzumbe Book Project, Morogoro, Tanzania. 165pp.

Morris, M. L and Bellon, M. R. (2004). Participatory plant breeding research: Opportunities and challenges for the international crop improvement systems. *Euphatica* 136: 21 - 5.

Mosha, D. B., Kajembe, G. C., Tarimo, A. K. P and Mbeyale, G. E. (2016). Performance of water management institutions in farmer managed irrigation schemes in Iringa Rural and Kilombero districts. *International Journal of Asian Social Science* 6(8): 430 - 445.

Mrema, E., Shimelis, H., Laing, M and Bucheyeki, T. (2016). 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., Kaaya, K. A., Araki, S., Otsuka, H and Nyadzi, I. G. (2003). Pedological characteristics, general fertility and classification of some benchmark soils of Morogoro, Tanzania. *African Journal of Science and Technology 4*(2): 101 - 112.

Ngailo, J. A. (2016). Rice farming in the Southern Highlands of Tanzania: Management practices, social economic roles and production contraints. *Europian Journal of Research in Social Science* 4(3): 3

Nwilene, F. E., Sanyang, S., Trao, A. K., Togola, A., Goergen, G and Agunbiade, T. A. (2008). *Rice stem borers: Biology, ecology and control.* Field Guide and Technical Manual. Cotonou, Benin: Africa Rice Centre (Warda). 28pp.

Nyeko, P and Alubayo, F. M. (2005). *Participatory assessment of farmers' experience of termite problem in agroforestry on Tororo district, Uganda.* News Letter No. 143. Agricultural research and extension network. 18pp.

Oben, E. O., Ntonifor, N. N., Kekeunou, S and Abbevtakor, N. M. (2015). Farmer's knowledge and perception on maize stem borers and their indigenous control methods in south western region of Cameroon. *Journal of Ethnobiology and Ethnomedicine* 11: 77.

Ogah, E. O. (2013). Evaluating the impact of new rice for Africa (NERICA) in the management of rice stem borers. *International Journal of Science* 1(5): 160 - 166.

Ogah, E. O., Echezona, B. C and Umeh, E. D. N. (2005). Effects of nitrogen fertilization and spacing on African rice gall midge, *Orseolia oryzivora* Harris and Gagne in a Sub-humid area of Southern Nigeria. *Journal of Agriculture, Food and Environmental Extension* 4(2): 15 - 18.

Pathak, M and Khan, Z. R. (1994). *Insect pests of rice*. International centre of insect physiology and ecology, International rice research institute (IRRI), Manila Philippines. 5 - 16pp.

Rhoades, R. E and Booth, R. H. (1982). Farmer back to farmer: A model for generating acceptable agricultural technology. *Journal of Agricultural Administration* 11: 127 - 137.

Rural livelihood development. (2009). *Improving rice profitability through increased profitability and better marketing focusing on Tanzania's central corridor.* Rice assessment and draft sector strategy of Tanzania. 37pp. [http://www.rldp.org/downloads/rice_strategy.pdf] site visited on 15/10/2017.

Sarwar, M. (2012). Effects of potassium fertilization on population build-up of rice stem borers (lepidopteron pests) and rice (*Oryza sativa* L.) yield. *Journal of Cerial Oil Seeds* 3(1): 6.

Sarwar, M., Ahmad, N and Tofique, M. (2011). Impact of soil potassium on population buildup of Aphid (Homoptera: Aphididae) and crop yield in Canola (*Brassica napus* L.) field. *Pakistan Journal of Zoology* 43(1): 15-19.

Saunders, M., Lewis, P and Thornhill, D. (2007). *Research Methods for Business Students* (4th edition). Prentice Hall, London. 226pp.

Sheikh, F. A., Khan, M. N., Sofi, P. A., Dar, Z. A., Sofi, N. R., Javaid, A and Bhat, M. A. (2017). Farmers' preference ranking in bush type of common bean (*Phaseolus vulgaris* L.) in Kashmir participatory varietal selection. *International Journal of Pure Applied Bioscience* 5: 712 - 719.

Sigsgaard, L. (2000). Early season natural biological control of insect pests in rice by spiders and some factors in the management of the cropping system that may affect this control. *Proceeding.* 19th European Colloquium of Arachnology, Århus. 57 - 64pp.

Singh, P., Singh, R., Dhaka, S. S., Kumar, D., Kumar, H and Kumar, N. (2015). Bioefficacy of insecticides and bio-pesticides against yellow stem borer, Scirpophaga incertulus (walk.) and their effect on spiders in rice crop. *South Asian Journal of Food and Technology Environment* 1(2): 179 - 183.

SPSS Inc. (Statistical Package for Social Sciences). (2016). SPSS users guide (Version 15). Chicago (IL): SPSS Inc.

Srivastava, S. K., Salim, M., Rehman, A., Singh, A., Garg, D. K., Prasad, C. S and Kamal, N. Q. (2000). Stem borer of rice-wheat cropping system: Status, diagnosis, biology and management. *Rice-Wheat Consortium Bulletin Series*. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi. 112pp.

Tefera, T. (2004). Farmers' perceptions of sorghum stem-borer and farm management practices in Eastern Ethiopia. *International Journal of Pest Management* 50(1): 35 - 40.

Wonnacott, T. H and Wonnacott, R. J. (1990). *Introductory Statistics for Business and Economics* (4^{th} edition). John Wiley and Sons, USA. 205pp.

CHAPTER THREE

3.0 DISTRIBUTION OF RICE STEM BORERS AND THEIR PARASITOIDS IN IRRIGATED LOW LAND RICE ECOSYSTEM IN KILOMBERO VALLEY, MOROGORO, TANZANIA

Published in *Journal of Entomology and Zoology Studies* 6(2): 237- 242

Abstract

Distribution of rice stem borers and their parasitoid, in irrigated low land rice ecosystem in Kilombero district, Morogoro, Tanzania was studied from March – July 2017 in randomly sampled thirty rice fields. Rice stem borer larvae were sampled at two growth stages of rice, the vegetative stage and reproductive stage using 1 m^2 quadrat. The study revealed the presence of one species of parasitoid from family Braconidae (*Cotesia flavipes*) which was found parasitizing the stem borer larvae. The density of borers (larvae), parasitoids and parasitism rates were respectively 103.82, 16.2 and 47.91% recorded during reproductive stage. Relatively lower values were recorded during the vegetative stage with mean density of 71.13 stem borers, 10.18 parasitoids and 36.39% parasitism rates. *Chilo* sp was highly parasitized compared to *Sesamia calamistis* due to their greater abundance. The Morisiter's index suggested an aggregated dispersion of both stem borers and parasitoids. The aggregation of borers and *C. flavipes* were recorded more at edges of the field than at the middle of the field suggesting their sources to be from other hosts rather than rice crop.

Key words: *Cotesia flavipes*, density, field parts, parasitism, rice growth stages, stem borers, Tanzania

3.1 Introduction

Stem borers particularly *Chilo* spp and *Sesamia calamistis* (Hampson) have been reported as major biotic constraints in cereals production in Sub-Saharan Africa where a potential yield loss of up to 73% can be incurred (De Groote, 2000). The stem borers have four stages of growth which includes egg, larvae, pupa and adult where larvae have been reported as the only destructive stage (Nwilene *et al*., 2008). The borers lay eggs at the basal of the leaf closer to the tips of leaf blades at the lower part of the leave blades where it takes about 3 – 4 days prior hatching (Pathack and Khan, 1994). The larvae craws upward along plants upon hatching where they can move to the neighbouring plants in between leaf sheath by the aid of wind or water through swimming and stay in the stem where they obtain food throughout the larvae stage (Adiroubane and Rajan, 2007). The larvae undergo several instars depending on the species (Harris, 1990) and temperature (Adiroubane and Rajan, 2007). Depending on stem borer species, the larvae stage may last for about 25 – 58 days and pupation for about 5 – 14 days (Maes, 1998). The first instar larvae of most stem borer species feed primarily on young and unfolded leaf tissues where older larvae feed internally by tunnelling the stem (Bosque-Pérez, Schulthess, 1998). Pupation occurs within stem, straw or stubble of the rice crop (Indike, 2002). In general, life cycle of many rice stem borers from egg to adult ranges from 42 to 83 days (Scrivastava *et al*., 2003).

Several groups of indigenous and exotic parasitoids such as Braconid and the Eulophid have been reported as most important parasitoids attacking stem borers in maize (*Zea mays* L. and sorghum (*Sorghum bicolar* L. Moench) fields (Mailafiya *et al*., 2009). These wasps lay about 65 white and wedge shaped eggs during single oviposition into the hemolymph of the larval host. The larvae can emerge from the egg into the hemolymph in as little as two to three days after oviposition (Sharkey, 2004). The larvae are pale yellow-white and grub-like in appearance. Upon emergence, the wasp larvae will undergo another larval molt (3rd instar) before spinning conspicuous white cocoons where they will develop into pupae and adults (Beckage *et al*., 1994). In Asia, Rami *et al*. (2002) have reported augmentation test for mass release of stem borer parasitoids such as *Trichograma japonicum* Ashmed, *Telenomus rowani* Gahan and *Tetrastichus schoenobii* Ferriere with some success in controlling rice stem borers' damages in China. In Africa, Moolman *et al*. (2013) reported *Bracon* sp (Hymenoptera: Braconidae) and *Cotesia sesamie* Cameron (Hymenoptera: Ichneumonidae), respectively, as parasitoids found parasitizing many stem borers species in Poaceae, Cyperaceae, Juncaceae and Typhaceae families in South Africa and Mozambique. These parasitoids belong to the Hymenopteran insects with highly specialized ovipositors for stinging and depositing eggs in the host. The host is affected through stinging effect that causes permanent paralysis in the host body (Mushore, 2005). The study by Cugala (Cugala, 2002) revealed *Trichogramma* spp as important parasitoids of eggs of stem borer species and *Cotesia* spp as important parasitoid of stem borer larvae in Zambia.

In Tanzania several stem borer parasitoids including *Cotesia* spp, *Dolichogenidea aethiopica* Wilkinson have been reported in maize and sorghum (Niyibigira *et al*., 2001). Similar or different parasitoids can be found in rice which can in future be used as important biological control. This important information was lacking under Tanzania contest. Among the parasitoids of stem borers, *Cotesia* spp have been reported as only parasitoid observed attacking multiple stem borers' species such as *Chilo* spp, *S. calamistis* and *Busseola fusca* Fuller (Degen, 2013). This parasitoid of Asian origin was introduced in Kenya in 1991 for classical biological control program where it was proved to reduce the population of *Chilo partellus* Swinhoe, *Chilo orichalcociliellus* Strand and *S. calamistis* by 30% in maize (*Zea mays* L.) crop (Overholt *et al*., 2002) and later was introduced in Sothern and Eastern African countries including Mozambique in 1996, Uganda and Somalia in 1997 (Overholt., 1998) and in Ethiopia in 1999 (Emana *et al*., 2001). In Tanzania *C. flavipes* was reported parasitizing *C. partellus* and *S. calamistis* in maize and sorghum crop (Niyibigira *et al*., 2001). The source of *C. flavipes* population in Tanzania is unknown but is most likely the source released by International centre of insect physiology and ecology (ICIPE) in Somalia, Kenya and Uganda (Emana, 2007; Dejen *et al*., 2013).

Parasitism of Lepidopteron stem borers by *C. flavipes* has been focused on only two cereal crop species which includes *Z. mays* and *S. bicolor* and four wild host plants which includes *Cyperus* spp, *Panicum* spp, *Pennisetum* spp and *Sorghum* spp (Sétamou *et al*., 2005, Mailafiya *et al*., 2011) but limited facts are available on stem borers parasitism in rice crop. Stem borer's density and parasitism rates may depend on growth stages of crop. Dejen *et al*. (2013) have reported the highest *C. partellus* larvae density and parasitism rates by *C. flavipes* during booting stage than harvesting stage in *Z. mays* and *S. bicolor* crops in Ethiopia providing the knowledge gap for studying population density and parasitism rates of stem borers in low land rice ecosystem in Tanzania.

Population density of borer pest complex in different growth stages of the rice plant would be useful to decide appropriate time for management practices such as insecticide application. This study, therefore, aimed at assessing the stem borers density and extent of *C. flavipes* parasitism at different growth stages of rice crop. Results obtained provided essential information on stem borer parasitism rates and or suggest the critical stages crop growth where parasitoids are to be released for regulation of population of stem borers in rice crop under field conditions.

3.2 Materials and Methods

3.2.1 Description of the study sites

The study was conducted in Kilombero district, Morogoro Tanzania from March – July 2017 in three wards which are under irrigated low land rice ecosystem viz; Signali (8° 0' 1.4234" S, 36° 50' 13.5179" E, 264m a.s.l), Mkula (7° 46' 4.2672" S, 36° 56' 43.4076" E, 261.27 m a.s.l) and Sanje (7° 45' 33.1981" S; 36° 55' 15.0247" E, 307.788 m a.s.l). From each ward ten farmers' fields of at least one acre and which are located at a distance of at least 0.5 km were selected for the study from each ward. Rice fields were divided into three equal parts (two edge parts and middle) where an equal number of plants with stem borer symptoms were randomly uprooted from each part (50 plants from each) along X/Y coordinates using the method of Niyibigira *et al*. (2001) for destructive sampling and dissected to remove medium to large (3^{rd} – 6^{th} instar) larvae from the stem. Sampling was conducted at 6 weeks after planting (vegetative) and 12 weeks after planting (reproductive) stage of rice growth.

The larvae were reared individually on small pieces of rice stems placed in glass vials (8.5 cm x 2.7 cm) at room temperature (26.9 ± 1^0C) and inspected every two days for mortality or parasitoid emergence (Zhou *et al*., 2003). Stems were replaced at each inspection to avoid fungal attack. The pupa stages were removed from the vial and placed in separate bottle plugged with cotton wool. All emerging adult moths were identified and then destroyed. The specimens of each emerged parasitoid species were labeled and preserved in 100% alcohol and sent to Sokoine University of Agriculture laboratory for identification. The emerged parasitoids were identified using identification guide as described by pathack and Khan (1994) and parasitism rates calculated using the method of Degen *et al*. (2013) as follows;

$$\% \text{ Parasitism} = \frac{\text{Number of parasitized larvae}}{\text{Total number of larvae}} \text{x}100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

3.2.2 Distribution of rice stem borers and their parasitoids

The spatial distribution pattern for stem borer and their parasitoids was determined by Morisita index of dispersion as described by Morisita (1959) and as modified by Amaral *et al*. (2014) as follows.

$$\text{Morisita's index } (I\delta) = \left(\frac{B-A}{A^2-A}\right) q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iv)}$$

Whereby $I\delta$ = Index or Coefficient of dispersion, q =Total number of plots sampled, A = Sum of species in each plot, B = Sum of squares of number of species in each plot. If $I\delta < 1$, $I\delta = 1$ and $I\delta > 1$ indicate uniform, random, and aggregated spatial distribution patterns, respectively.

3.2.3 Data collection and analysis

Data collected under this study were the number of stem borer larvae and number of parasitoids per strata. Stem borer density and parasitoids density were analyzed using R software and bar charts drawn using excel software. Spatial distribution of both stem borer and parasitoids were established using Morisita index of dispersion as described by Morisita (1959) and as modified by Amaral *et al*. (2014). The Parasitism rates were calculated from each ward, field part and growth stages of rice crop and subjected to R statistical software for analysis. During analysis a randomized complete block design (RCBD) in a split plot were considered where wards were regarded as main plot and field parts as subplots. Analysis were done separately for each plant growth stage. Means were separated using Fishers Least Significant difference (LSD) at $p \leq 0.05$. Regression analysis was performed using Excel to determine relationship between stem borer density and parasitism rates.

3.3 Results

3.3.1 Distribution of rice stem borers and their parasitoids

Morita's dispersion index for stem borer larvae indicated that there was more number of stem borer larvae of rice at vegetative stage in three wards of Signali, Mkula and Sanje with an aggregate distribution of both stem borer larvae and parasitoids (Table 3.1).

Table 3.1: Effect of locations and rice growth stage on dispersion index of rice stem borers and their parasitoids

Ward	Morisita's Index for stem borers larvae		Morisita's Index for parasitoids	
	Vegetative	Reproductive	Vegetative	Reproductive
Signali	9.673	8.542	13.562	11.472
Mkula	9.323	8.289	14.547	13.008
Sanje	9.088	8.589	17.374	13.265

KEY: If $I\delta < 1$, $I\delta = 1$ and $I\delta > 1$ indicate uniform, random, and aggregated spatial distribution patterns respectively

3.3.2 Stem borer larvae and *C. flavipes* density within rice field

There were significant differences (F = 8.62; df = 2, 4; *P* = 0.04) in mean stem borer and *C. flavipes* density between field parts (Fig 3.1 and 3.2). The highest stem borer and *C. flavipes* density was recorded from edges of the rice field than from the middle of the fields regardless of the rice phenological stages.

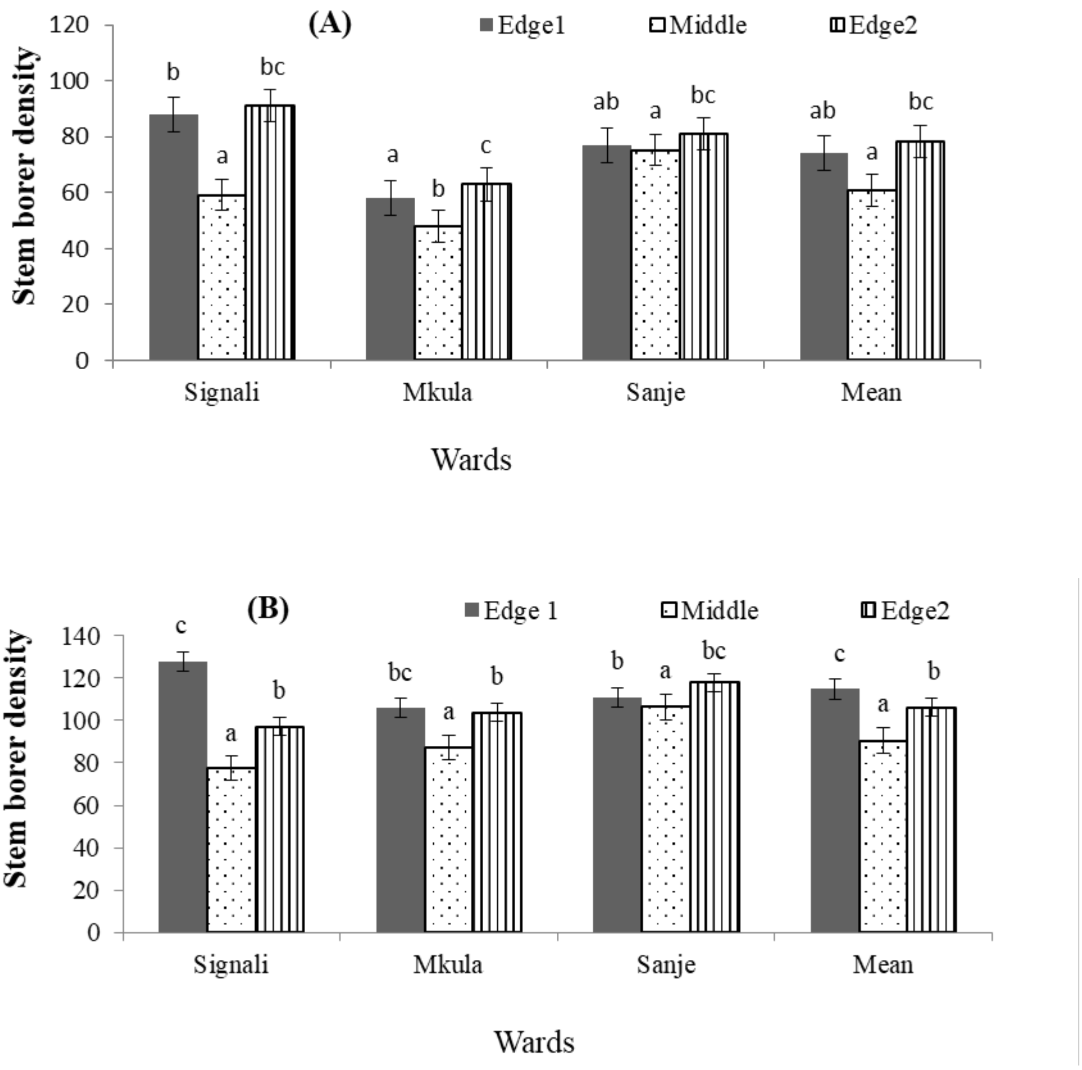
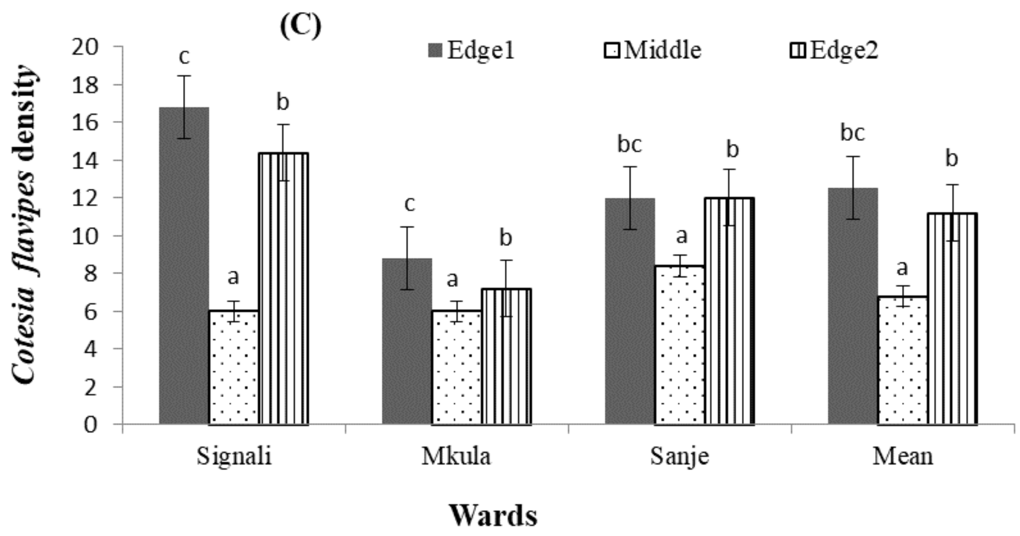


Figure 3.1: Stem borers' aggregation within rice field

Bars with the same letter are not significant ($P < 0.05$) using Fisher's Least Significant difference test**.** Figures with letters (A) and (B) represents records of stem borer density at vegetative and reproduction stages of rice growth respectively.



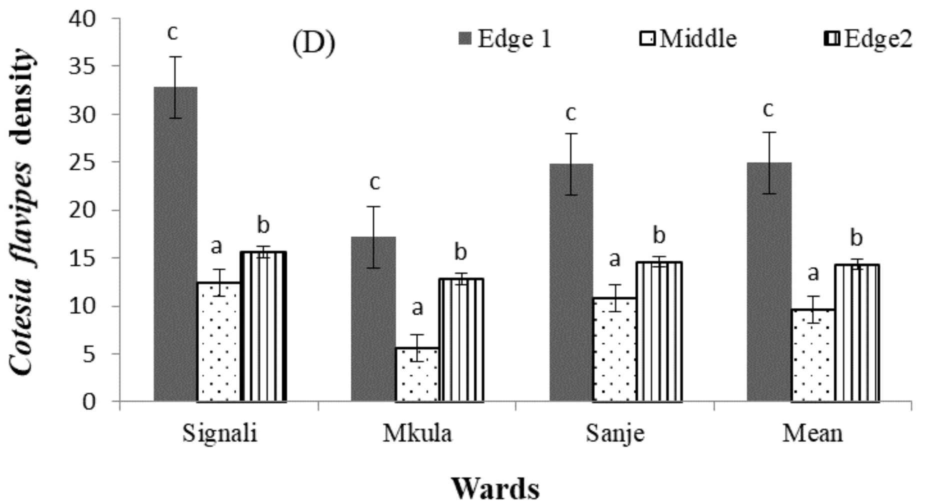


Figure 3.2: ***Cotesia flavipes'*** **aggregations within rice field**

Bars with the same letter are not significant (P < 0.05) using Fisher's Least significant difference test. Figures with letters (C) and (D) represents records of *C. flavipes* at vegetative and reproduction stages of rice growth respectively.

3.3.3 Stem borers larvae parasitism in wards

The rate of stem borer parasitism by *C. flavipes* was statistically similar across locations (P > 0.05) in all rice growth stages (Table 3.2).

Table 3.2: Stem borer's parasitism in wards

Wards	Percentage stem borer parasitism rates (Mean ± SE)					
	Chilo sp		***S. calamistis***		**Total**	
	Vegetative stage	**Reproductive stage**	**Vegetative stage**	**Reproductive stage**	**Vegetative stage**	**Reproductive stage**
Mkula	33.17 ± 0.91a	37.57 ± 0.91a	1.46 ± 3.11a	5.26 ± 0.62a	34.63 ± 1.39a	42.83 ± 2.63a
Sanje	32.61 ± 0.86a	43.61 ± 1.21a	2.81 ± 1.89a	5.65 ± 0.31a	35.42 ± 1.52a	49.26 ± 0.97a
Signali	35.57 ± 0.89a	48.25 ± 1.46a	3.57 ± 3.37a	3.39 ± 0.23a	39.14 ± 2.91a	51.64 ± 1.49a
Mean	33.78	43.14	2.61	4.77	36.39	47.91
P - value	0.957	0.087	0.731	0.91	0.816	0.725

Means within columns followed by the same letters do not differ significantly ($P < 0.05$) (LSD)

3.3.4 Rate of stem borer parasitism by *C. flavipes* in field parts

There were significant differences between field parts samples in rate of stem borer's parasitism in vegetative stage (F = 1.48; df = 2, 4; *P* = 0.035) and during reproduction stage (F = 6.41; df = 2, 4; *P* = 0.038) during reproduction stage) (Table 3.3). The rate of parasitism was high at the edge of the rice fields sampled than at the middle of the field both at vegetative and reproductive stages.

Table 3. 3: Stem borers parasitism in field parts

Field part	Percentage parasitism (Mean ± SE)	
	Vegetative	Reproduction
Edge 1	45.5 ± 8.81b	67.5 ± 12.82b
Edge2	44.9 ± 7.70b	52.46 ± 8.90ab
Middle	18.77 ± 5.19a	23.77 ± 6.54a
Mean	36.39	47.91
P - value	0.035	0.038

Means within columns followed by the same letters do not differ significantly (*P* > 0.05) (LSD)

3.3.5 Relationship between *C. flavipes* parasitism rates and stem borer density

Rate of parasitism of stem borers by C. *flavipes* was directly correlated to stem borer density (Fig. 3.3) both at vegetative and reproductive growth stage of rice. The parasitism rates increases as stem borer density was increased.

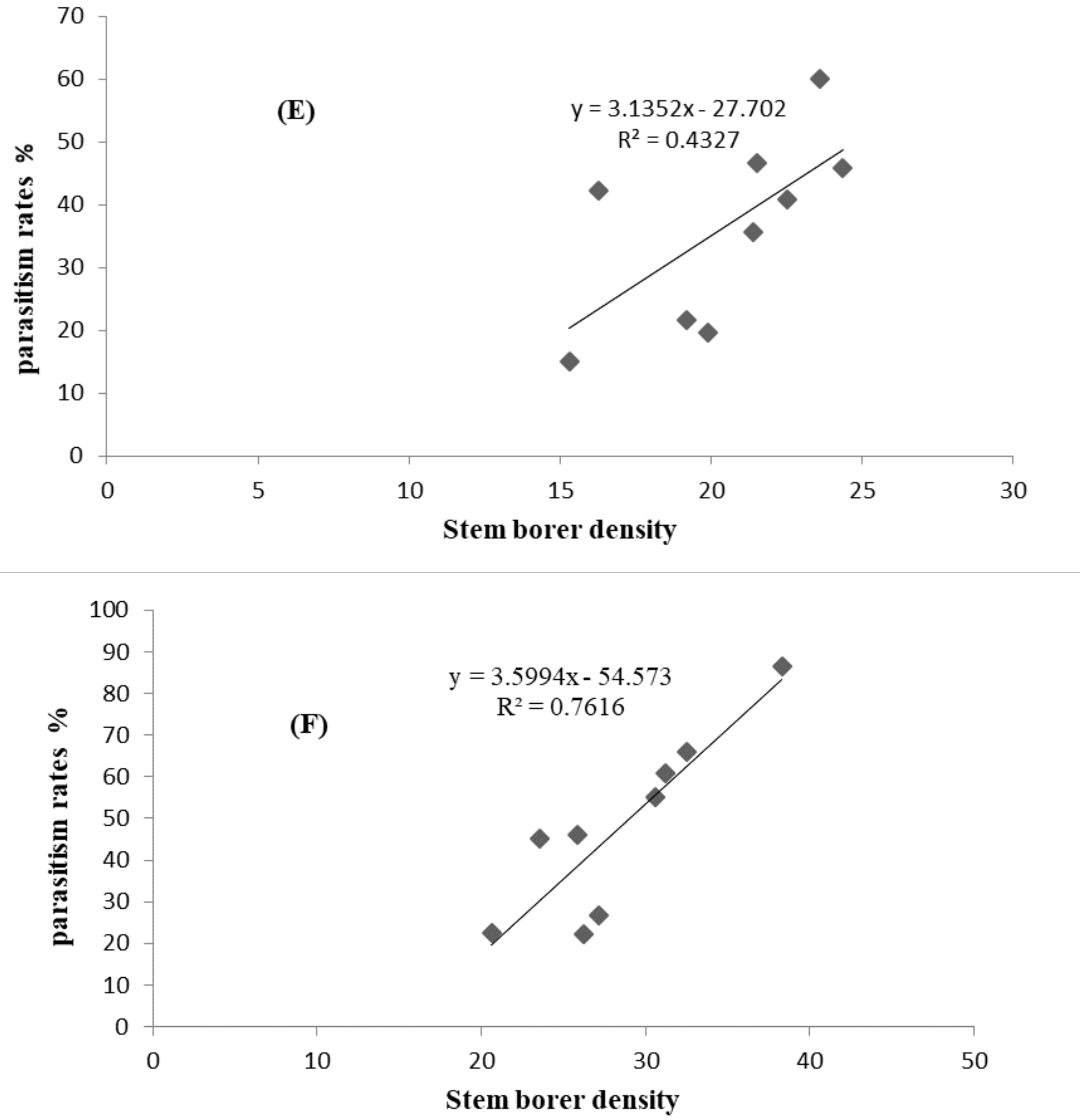


Figure 3.3: The relationship between stem borer density and *C. flavipes* parasitism efficiency

The 9 points in the graph showed mean of three wards in three field parts. Figures with letters (E) and (F) represents records of stem borer density at vegetative and reproduction stages of rice growth respectively

3.4 Discussion

The results under this study reported the highest density of stem borers larvae stages and parasitoids in the edge parts than middle parts of the field in all three wards surveyed.

These findings are in parallel with the study of Casey and Trumble (2012) who reported that for the development of sampling plan, one should concentrate on the edge of the field because it is where the borers are accumulated. Concentration of borers and parasitoids in edge parts of the field implies that the borers come from alternative host plants which are around the field. Gounou and Schulthess (2004) reported distribution and aggregation of stem borers in various plant hosts assessed which are in line with the findings of this study. This is further reinforced by the study of Harris (1990) who reported cereal stem borers as polyphagous in nature for their behavior of attacking several gramineous and other non-cultivated wild host plants. Le Ru *et al*. (2006) reported several wild host plants of stem borers in East Africa including Poaceae, Cyperaceae and Typhaceae which are also found in Kilombero district. These alternative host plants were probably the sources of stem borer's reservoirs for rice crop under the study area. Showler *et al*. (2011) reported the higher abundance and diversity of Mexican rice borer (*Eoreuma loftini* Dyar) in sugarcane field infested with grasses and broad leaf weeds or mixture of both weed types as compared to weed free sugarcane field.

The density of stem borers and C. *flavipes* under this study were observed high at reproduction stage than at vegetative stage of rice growth. Consistent with the results in this study, Litsinger *et al*. (2007) also observed higher stem borer larvae density during reproduction than vegetative stage of maize crop suggesting the reason being the assurance of borers in getting more nutritious food in stem at reproduction/tasselling stage of maize. They also reported high larvae parasitism rates during reproduction stage than in vegetative stage which implies high density of the parasitoids in late stages than early stages of maize growth. The findings of this study are further supported by BRRI (2007) which described various ecological factors including plant ages as among factors affecting fluctuation of pest and natural enemies in rice ecosystem. In addition, Wale *et al*. (2006)

reported the population of ants which were commonly seen preying on *Busseola fusca* Fuller of sorghum in Ethiopia increased with crop phenology. Against the findings of this study, Rahman *et al*. (2014) reported stem borer hunting spiders reach peak during 60 to 75 days after transplanting and their population further declines with the age of the crop.

The study showed aggregation distribution of stem borers (larvae) and that *C. flavipes* within the fields according to Morisita index where it was greater than one in all wards surveyed. This agrees with the study of Leonard and Rwegasira (2015) who reported aggregated distribution of stem borer larvae in rain fed rice ecosystems in different wards of Kahama District in Tanzania.

Highest parasitism rates were recorded in Signali in both rice phenology but not significantly different among wards. The similarities in parasitism rates can be due density of borers of similar trends in both wards and in both field parts. This agrees with the study of Elliott *et al*. (2002) who reported the abundance of natural enemy populations to increases with increase in host population. According to this study, the density of borers and parasitoids were high at the edge parts than at the middle of all fields surveyed where highest parasitism was also recorded. The reasons would probably due to edge parts of the field being closer to natural habitats with alternative hosts which ensure availability of enough food for assurance of parasitoids survival. Maliafiya *et al*. (2011) reported natural habitat as essential means of providing refuges for some parasitoid species for stem borers. Parasitism of borers by *C. flavipes* was highly recorded at reproduction stage than vegetative stage. This was in line with the study of Degen (2013) who reported high parasitism rates of *C. flavipes* on sorghum stem borer (*C. partellus*) larvae in Ethiopia during booting stage than harvesting stage of sorghum. In addition Sow *et al*. (2013) described a significant correlation between *Cotesia plutellae* Kurdjumov (Braconidae), a larval parasitism rates of Diamond back moth (*Plutella xylostella* L.) with the age of cabbage which is also in line with the findings of this study. This study reports for the first time on parasitism of stem borers by *C. flavipes* in rice crop in Tanzania with parasitism rates of 36.4% - 47.9%. Previous study recorded parasitism rates of 3.9% and 1.9% in Zanzibar (Niyibigira *et al*., 2001); 76.4% in Kenya (Maliafiya *et al*., 2011) 31% in Uganda (Matama *et al*., 2007); 73% in Ethiopia (Mulugeta, 2001) and 30% in India (Divya *et al*., 2009) which were all from maize and sorghum crop.

The present study revealed a significant positive relationship between parasitism rates of *C. flavipes* and stem borers density. This was parallel with the study of Maliafiya *et al*. (2010) who reported that under normal circumstances the parasitoid richness are positively correlated with borers abundance. The results of this study are further supported by the study of Matama *et al*. (2007) who reported a positive association between percentage parasitism of *C. flavipes* and population density of *C. partellus* in Sorghum and Maize crops in Uganda.

3.5 Conclusions

The findings from this study revealed the presence of two stem borer species (*Chilo* spp and *S. calamistis*) and one species of Braconoid wasp (*Cotesia flavipes*) in which their densities varied with crop phenology and field parts. The rate of parasitism of stem borers by C. *flavipes* was directly correlated to stem borer density.

Acknoledgements

This study was supported by USAID Feed the Future IPM Innovation Lab, Virginia Tech, Cooperative Agreement No. AID-OAA-L-15-00001 through International Centre of Insect physiology and Ecology (ICIPE). Thanks are due to farmers and extension officers in the study area for willingly working with us to undertake the study in their farms.

References

Adiroubane, D and Raja, K. (2007). Stem borer, *Scirpophaga incertulus* (Walker). *Journal of rice Research* 3: 11 - 18.

Amaral, M. K., Pellico, N. S., Lignu, C and Figueiredo, F. A. (2014). Evaluation of the morisita index for determination of the spatial distribution of species in Afragment of Araucaria forest. *Applied Ecology and Environmental Research* 13: 361 - 372.

Bangladesh Rice Research Institute (BRRI) (2007). *Annual Report*. 142- 146pp.

Casey, D. B and Trumble, J. T. (2012). Spatial dispersion and binomial sequential sampling for the potato psyllid (Hemiptera: Triozidae) on potato. *Journal of Pest Management* 68: 865 – 869.

Beckage, N. E, Tan, F. F., Schleifer, K. W., Lane, R. D and Cherubin, L. L. (1994). Characterization and biological effects of *Cotesia congregata* polydnavirus on host larvae of the tobacco hornworm, *Manduca sexta*. *Archives of Insect Biochemistry and Physiology* 26: 165-195

Bosque-Pérez, N. A and Schulthess, F. (1998). *African cereal stem borer's economic importance, taxonomy, natural enemies and control in West and Central Africa*. CABI International, Wallingford. 26 – 45pp.

Cugala, D. (2002). Introduction and establishment of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) in Mozambique as a biological control agent against cereal stem borers in Mozambique. Maters of Philosophy Thesis, University of Zimbabwe, Harare, Zimbabwe. 220pp.

De Groote, H. (2002). Maize yield losses from stalk borers in Kenya. *Insect Science Application* 22: 89 – 96.

Dejen, A., Getu, E., Azerefegne, F and Ayalew, A. (2013). Distribution and extent of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) parasitism in Northeastern Ethiopia. *International Journal of Insect Science* 5: 9 - 19.

Divya, K., Marulasiddesha, K. N., Krupanidhi, K and Sankar, M. (2009). Population dynamics of spotted stem borer, *Chilo partellus* (Swinhoe) and its interaction with natural enemies in sorghum. *Indian Journal of Science and Technology* 3: 70 – 4.

Elliott, N. C., Kieckhefer, R. W., Michels, G. J and Giles, K. L. (2002). Predator abundance in alfalfa fields in relation to aphids, within-field vegetation, and landscape matrix. *Environmental Entomology* 31(2): 253 - 260.

Emana, G., Overholt, W. A and Kairru, E. (2001). Distribution and species composition of stemborers and their natural enemies in Ethiopia. *Insect Science Application* 21: 353 – 9.

Emana, G. (2007). Comparative studies of the influence of relative humidity and temperature on the longevity and fecundity of the parasitoid, C*otesia flavipes*. *Journal of Insect Science* 7(19): 1 – 7.

Gounou, S and Schulthess, F. (2004). Spatial distribution of lepidopterous stem borers on indigenous host plants in West Africa and its implications for sampling schemes. *Journal of African Entomology* 12 (2): 171 - 178.

Harris, K. M. (1990). Bioecology of sorghum stem borers. *Insect Science Application* 11(4/5): 467 - 477.

Indike, A. (2002). Analysis of pest management methods used for Rice stem borer (*Scirpophaga incertulas*) in Sri Lanka based on the concept of sustainable development. Thesis for award of Master's Degree at Lund University, Maharagama, Colombo, Sri Lanka. 137pp.

Leonard, A and Rwegasira, G. M. (2015). Abundance and spatial dispersion of rice stem borer species in Kahama, Tanzania. *Journal of Insect Science* 15(1): 132.

Le Ru, B. P., Ong'amo, O. G., Moyal, P., Muchugu, E., Ngala, L., Musyoka, B., Abdullah, Z., Matama-Kauma, T., Yahya Lada, Z. V., Pallangyo, B., Omwega, C. O., Schulthes, F., Calatayud, P.A and Silvain, J. F. (2006). Geographic distribution and host plant ranges of East African noctuid stem borers. *Journal of Insect Science* 42: 353 - 361.

Litsinger, J. A., Dela Cruz, C. G., Canapi, B. L and Babrion, A. T. (2007). Maize planting time and arthropod abundance in Southern Mindanao, Philippines. *International Journal of Pest management* 53(2): 147 – 159.

Maes, K. V. N. (1998). *Cereal stem borers: Pyraloidea: Crambidae, economic importance, taxonomy, natural enemies and control*. CABI International. 87 – 98pp.

Mailafiya, D. M., Le Ru, B.P., Kairu, E.W., Calatayud, P.A and Dupas, S. (2009). Species diversity of lepidopteran stem borer parasitoids in cultivated and natural habitats in Kenya. *Journal of Applied Entomology* 133: 416 - 429.

Mailafiya, D. M., Le Ru, B. P., Kairu, E. W., Calatayud, P. A and Dupas, S. (2010). Factors affecting stem borer parasitoid species diversity and parasitism in cultivated and natural habitats. *Environmental Entomology* 39: 57 - 67.

Mailafiya, D. M., Le Ru, B. P., Kairu, E. W., Calatayud, P. A and Dupas, S. (2011). Parasitism of lepidopterous stem borers in cultivated and natural habitats. *Journal of Insect Science* 11: 15.

Matama, K. T., F. Schulthess., J. A. Ogwanga., J. M. Mueke, and C. O. Omwega. (2007). Distribution and relative importance of lepidopteran cereal stemborers and their parasitoids in Uganda. *Phytoparasitica* 35(1): 27 – 36.

Moolman, H. J., Van den Berg, J., Conlong, D., Cugala, D., Siebert, S. J and Le Ru, B. P. (2013). Diversity of stem borer parasitoids and their associated wild host plants in South Africa and Mozambique. *Phytoparasitica* 41 (1): 89 – 104.

Morista, M. (1959). Measuring the dispersion of individuals and analysis of distributional patterns. *Journal of Ecological Biology* 2: 215 – 235.

Mulugeta, N. (2001). Survey of parasitoids on lepidopterous stemborers attacking maize and sorghum in some localities of Ethiopia. *Ethiopian Journal Pest Management* 5: 69 – 75.

Mushore, K. (2005). Assessment of suitability of different populations of stemborer species for the development of *Cotesia flavipes* (Hymenoptera: Braconidae) and the establishment of the latter in Zimbabwe. Thesis for Award of PhD Degree at University of Zimbabwe. 114pp.

Niyibigira, E. I., Abdallah, Z. S., Overholt, W. A., Lada, V. Y and Van Huis, A. (2001). Distribution and abundance of lepidopteran stem borers and associated indiginous parasitoids in maize and sorghum in Zanzibar. *Insect Science Application* 21: (4) 335 – 346.

Nwile, F. E., Sanyang, S., Taroe, A. K., Tagola, A., George, G and Agunbbiade, T. A. (2008). *Rice stem borers: Biology, ecology and control*. Field Guide and Technical Manual. Africa Rice Center (WARDA), Cotonou, Benin. 28pp.

Overholt, W. A. (1998). *Biology, economic importance, Taxonomy, Natural enemies and control of African cereal stemborers*. Wallingford, UK. CABI International. 349 – 62pp.

Overholt, W. A., Ngi-Song, A and Omwega, C. O. (2002). An ecological approach to biological control of gramineous stemborers in Africa: The introduction and establishment of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). http://ipmworld.umn.edu/chapters/overholt.htm] site visited on 15/09/2017).

Pathak, M and Khan, Z. R. (1994). *Insect pests of rice*. International centre of insect physiology and ecology. International Rice Research Institute. Manila., Philipines. 5 - 16pp.

Rahaman, M. M., Islam, K. S., Jahan, M. A. A and Mamun, M. A. A. (2014). Relative abundance of stem borer species and natural enemies in rice ecosystem at Madhupur, Tangail, Bangladesh. *Journal of Bangladesh Agricultural University* 12(2): 267 – 272.

Rami, K., Overholt, W. A., Khan, Z. R and Polaszek, A. (2002). Biology and management of economically important Lepidopteran cereal stem borers in Africa. *Annual Review of Entomolog* 47: 701 – 731.

Sétamou, M., Jiang, N and Schulthess, F. (2005). Effect of the host plant on the survivorship of parasitized *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) larvae and performance of its larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). *Biological Control* 32: 183 - 190.

Sharkey, M. J. (2004). Synopsis of the Agathidinae (Hymenoptera: Braconidae) of America north of Mexico. *Proceedings of the Russian Entomological Society* 75(1): 134–52.

Showler, A. T., Beuzelin, J. M and Reagan, T. E. (2011). Alternate crop and weed host plant oviposition preferences by the Mexican rice borer (Lepidoptera: Crambidae). *Crop Protection* 30: 895 - 901.

Sow, G., Diarra, K., Arvanitakis, L and Bordat, D. (2013). The relationship between the diamondback moth, climatic factors, cabbage crops and natural enemies in a tropical area. *Folia Horticulturae* 3: 12.

Srivastava, S. K., Salim, M., Rehman, A., Singh, A., Garg, D. K., Prasad, C. S., Gyawali, B., Jaipal, B and Kamal, N. Q. (2003). *Stem borer of rice-wheat cropping system: Status, diagnosis, biology and management*. Rice-Wheat Consortium bulletin series. Rice-wheat Consortium for the Indo-Gangetic Plains. New Delhi. 112pp.

Wale, M., Schulthess, F., Kairu, E. W and Omwega, C. O. (2006). Cereal yield losses caused by lepidopterous stemborers at different nitrogen fertilizer rates in Ethiopia. *Journal of Applied Entomology* 130(4): 220 – 229.

Zhou, G., Overholt, W. A and Kimani-Njogu, S. W. (2003). Species richness and parasitism in assemblage of parasitoids attacking maize stem borer in Coastal Kenya. *Ecological Entomology* 28: 109 – 118.

CHAPTER FOUR

4.0 LEPIDOPTERAN STEM BORER SPECIES ABUNDANCE AND ASSOCIATED DAMAGES IN IRRIGATED KILOMBERO LOW LAND RICE ECOSYSTEM IN TANZANIA

Published in *Journal of Entomology* 15 (1): 28 - 35. doi:10.3923/je.2018.28.35

Abstract

Rice stem borers are among the most biotic stresses of economic importance in agriculture. Little was known about stem borer problem in Tanzania prior to this study. Understanding stem borer abundance and damages would help to design appropriate stem borer integrated pest management strategy in rice. This study was aimed at investigating rice stem borer's species abundance and their associated damages in irrigated lowland rice ecosystem in Kilombero Tanzania. Field survey study on rice stem borer abundance and incidences were conducted in farmer's fields on selected rice varieties at varied growth stages in Kilombero district under irrigated rice schemes. Adult moths were trapped by light traps and incidences assessed based on dead hearts and white head in 1 m^2 quadrat in field stratum sampled at random. Results indicated the presence of *Chilo* sp and *Sesamia calamistis* in all study areas with *Chilo* sp as most abundant species (79.24% – 92.05%) followed by *S. calamist* (7.97% - 20.77%). The abundance of these two stem borer species and their associated damage incidences varied significantly ($P > 0.05$) between rice varieties and rice growth stages. The insecticides sprayed on different rice varieties had neither effect on species abundance nor on incidences of stem borers under the study area suggesting that the sprayed insecticides did not control the pest. This study, therefore, concluded that control measures particularly IPM is highly recommended short of which the control of stem borer will in future be unachievable.

Key words: *Chilo* sp, damage incidences, insect abundance, Kilombero rice schemes, *Sesamia calamistis*, Tanzania

4.1 Introduction

Abiotic (soil fertility, salinity and drought) and biotic (pests and diseases) stresses are known to affect rice production in Tanzania. Insect pests are among major biotic stresses of agricultural concern (Rahaman *et al.*, 2014). More than 100 species of insects are known to attack rice crop where 20 of them are of economic importance (Pathak, 1997). Stem borers have been reported the most devastating pests of economic importance in rice (Bawo *et al.,* 2001; Banwo, 2002). About four rice stem borers species are known to infest rice in Africa. The species includes *Chilo sp, Diopsis longcornis* Macquart, *Maliarpha separatalla* Ragonot and *Sesamia calamistis* Hampson (Rami *et al*., 2002; Ogah, 2013). These stem borers have been reported to occur in 17 tropical African countries (Ismaila, 2010). In Tanzania three rice stem borer species have been reported from Morogoro, Kahama, Mwanza, Mbeya, Shinyanga and Zanzibar. These includes white stem borer (*M. seperatella*), the pink stem borer (*S. calamistis*) and spotted stem borer (*Chilo partellus,* Swinhoe) (Banwo, 2002; Leonard and Rwegasira, 2015).

Rice grain yield loss of up to 80% has been reported to be incurred where there are heavy stem borer's infestations under field conditions (Muralidharan *et al*., 2005). The abundance, distribution and damage of these stem borer species vary between different ecological zones (Ogah, 2013), within host plants (Addo-Bediako and Thanguane, 2012) and within crop growth stages (Indike, 2002). The dead heart symptoms and white head symptoms are two damage symptoms manifested by stem borer caterpillar damages, the former being caused by borers attack during vegetative stage and the later caused by borers attack during flowering stage (Pathak and Khan, 1994). Dead heart damage symptom are recognized by presence of whitish or discoloured area at feeding site of leaf blade where the stem turns brown, wilts and dry at late stage while the white head symptoms can be recognized by presence of white or brown panicles with empty spikelets (Indike, 2002).

In Tanzania rice stem borers abundance ranges from 16% to 70%, dead heart and white head incidences of of 7.8% and 2.9% respectively have been reported in rain fed lowland rice ecosystem of the Lake Zone (Leonard, 2015). Being rain fed, the crop is grown only once per year. Little was known about stem borer incidences in irrigated low land rice ecosystem where rice crop is continuously cultivated like the Kilombero valley. In this area the stem borer problem could be bigger that perceived but facts to support this were to be established. Understanding stem borer abundance and extent of damages would help to design appropriate stem borer integrated pest management strategy in rice. This study, therefore, reports on stem borer species diversity, abundance and their associated damages in irrigated lowland rice of Kilombero.

4.2 Materials and Methods

4.2.1 Description of the study site

The study was conducted from December 2016 to June 2017 in Kilombero irrigated rice schemes, Morogoro, Tanzania. The three wards that were covered in the present study were located at about 20 km from each other. The study locations included Signali (8° 0' 1.4234" S, 36° 50' 13.5179" E with 264m a.s.l), Mkula (7° 46' 4.2672" S, 36° 56' 43.4076" E with 261.27 ma.s.l) and Sanje (7° 45' 33.1981" S; 36° 55' 15.0247" E with 307.788 ma.s.l.) (Fig. 4.1).

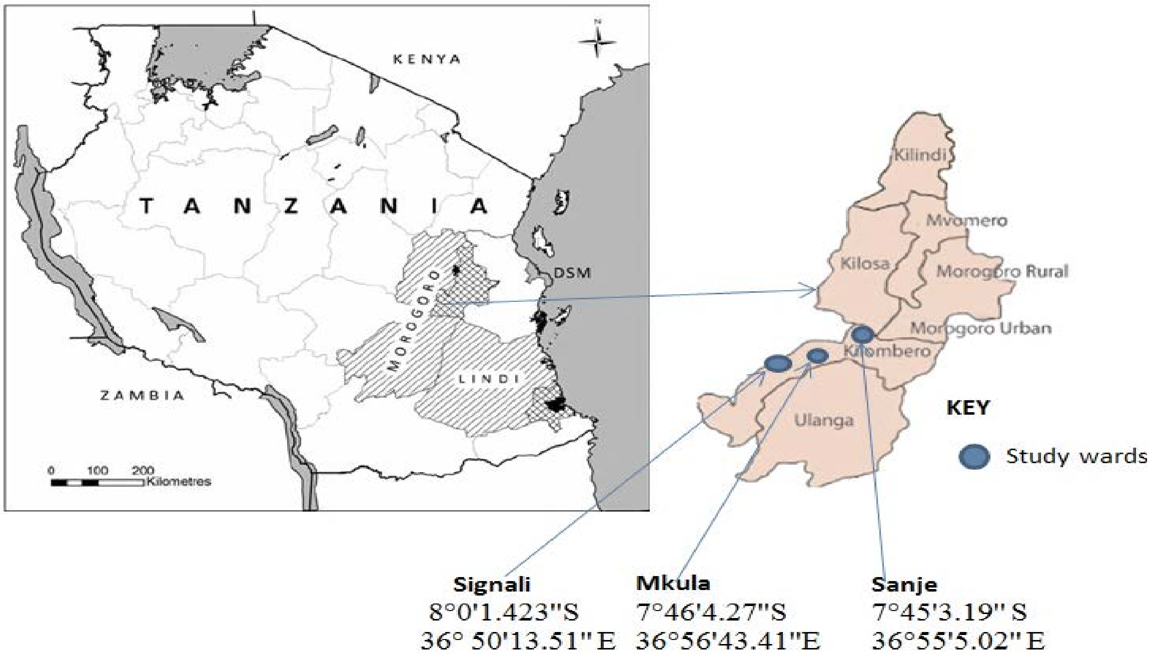


Figure 4.1: Map of Tanzania showing the three studied wards in Kilombero district

In these wards rice is intensively cultivated under irrigation system and water availability is assured throughout the year. Twenty four fields, 8 fields in each ward were randomly selected and kept under surveillance for adult moth's species and associated larval damages. A randomized complete block design in a split plot was assumed during the survey where wards were considered as main plot and farmer's fields as subplots while each ward represented a replication. The plot size in each field was 1 acre (70 m x 70 m) and the distance from one field to the other was at least 0.5 Kilometre.

Data were collected from four commonly grown rice varieties, namely; SARO5, SUPA, Mbawa mbili and Lawama in each ward. These were the commonly grown varieties that were available in each ward. Fields sprayed or not sprayed with insecticides were also considered separately as management practices during data collection. In every ward four fields which were not sprayed with any insecticides in four rice varieties (SUPA, Mbawa mbili and Lawama) and four fields sprayed with insecticides in again four rice varieties

(SUPA, Mbawa mbili and Lawama) were selected for data collection. The insecticides recorded and which are commonly used by farmers in the study area were Karate and Kung'fu which both have a common active ingredient the Lambda cyhalothrin.

4.2.2 Stem borer species abundance and distribution in the study area

Sampling for stem borer incidences was done at 6 weeks after planting (vegetative stage) and repeated at 12 weeks after planting, just before ripening stage (reproductive stage). Trapping of borers to assess their abundance was done following the method of Leonard and Rwegasira (2015) with some modification. The modification was the use of light traps embedded in plastic containers instead of white cloth. The light traps with white and black light sources were embedded in a 6-litre plastic container which was cut half way at the middle leaving the mouth funnel and mounted in upside down on another container of the same size without cuttings for collection of insects. The containers were painted in black colour outside but in white colour inside for light reflection. Each field was devided into three eaqual parts and one trap placed at centre of each field part. The traps were hanged on a wooden stand and the lights switched on for attraction of adult moths. Trapping was done for two hours from 19:00hrs – 21:00 hrs East African time.

Moth species were collected in down container through funnel like mouth of the upper container. Moths that were found gathering in the upper containers were picked by hand. All the moth species that fell in the container through the funnel and hand collected from the trap were transferred to another well labelled container containing 75% Ethyl Acetate and sorted letter for species identification. The identification of species was done using the identification guide (Pathack and Khan, 1990). The number of moth species recorded were the average of the three traps from each field. Species composition was calculated according to Rahaman *et al.* (2014) method as follows;

$$\text{Species composition} = \frac{\text{Number of individual species in a sample}}{\text{Total number of of individual of all borer species}} \text{X100} \quad \text{………..…. (v)}$$

4.2.3 Assessments of rice stem borers' incidence in farmers' fields

The sampled farmers' field were divided into four equal sized strata where in each stratum, four 1 m^2 quadrats were set for assessment of incidences which gave a total of 16 quadrats (Leonard, 2015). The assessment was done twice, at 42 days after planting (vegetative stage) for dead heart damage and near physiological maturity (84 days after planting) for white head damage (Niyibigira *et al*., 2001). The incidences were calculated following the method described by Suresh *et al.* (2009) as follows:-

$$\text{Stem borer incidence \%} = \frac{\text{Number of dead hearts or white heads}}{\text{Total number of productive tillers}} \text{ X100} \quad \text{..…….. (vi)}$$

4.2.4 Data collection

The collected data were on existing species of stem borers, their composition through trap for quantification across the study areas, number of tillers/m^2 (damaged tillers and undamaged tillers) and number of panicles/m^2 (damaged and undamaged) for estimation of incidences. The incidence data were tested for normality using R software (2016) and found to conform to normal distribution and therefore there was no need for transformation. When tested for stem borer species composition, the data on *S. calamistis* were found not normally distributed and therefore normalized by log transformation prior to analysis.

4.2.5 Data analysis

The data for stem borers species composition and damage incidences were subjected to analysis of variance (ANOVA) using R statistical software and means separated using the

Fisher' Least significant difference at $P \leq 0.05$ level. The main plot error was used to test the effect of main plot factors. The analysis model was according to Gomez and Gomez (1984) for split plot layout, i.e. $Y_{jkm} = \mu + R_i + A_j + \alpha ij + Bk + AB_{jk} + \beta_{ijk}$; Where: Y_{ijkm} = Response on stem borer abundance or incidence in different wards and in different fields, μ = General mean, Ri = Replication effect, Aj = Effect of j^{th} ward on stem borer abundance or incidence, αij = Error for j^{th} ward, Bk = Effect of k^{th} field on stem borer abundance or incidence, AB_{jk} = Interraction effect on j^{th} ward and k^{th} field and βijk = error for k^{th} field.

4.3 Results

4.3.1 Species abundance in wards

Two species of stem borers, *Chilo* sp and *S. calamistis* were recorded from all the surveyed sites. There were significant differences in mean species composition among the wards for *Chilo* sp (F = 2.72; df =2, 18; P = 0.012) and for *S. calamistis* (F = 5.17; df = 2, 18; P = 0.017) (Table 4.1). *Chilo* sp was found highly abundant than *S. calamistis* in all three wards surveyed. Among the wards surveyed, the highest abundance of *Chilo* sp was recorded in Signali followed by Mkula and Sanje. Abundance records for *S. calamistis* was highest in Signali and least in Mkula and Sanje.

Table 4.1: Abundance of stem borers species in wards

Wards	**Percentage stem borer species (Mean ± SE)**	
	***Chilo* sp**	***Sesamia calamistis***
Signali	92.05 ± 2.7b	7.95 ± 2.70a
Mkula	90.71 ± 2.5b	9.29 ± 2.65ab
Sanje	79.24 ± 0.73a	20.77 ± 3.24b
C.V	5.1	7.9
P - value	0.012	0.017

Means for *Sesamia. calamistis* were log transformed prior analysis and values are reconverted in original scale. Values followed by the same letters in a column are not statistically different (P < 0.05) LSD.

4.3.2 Species abundance in insecticide treated fields

The abundance for *Chilo* sp was higher than that of *S. calamistis* in all four rice varieties and in both insecticide sprayed and unsprayed rice fields (Table 4.2). There was no significance differences for the *Chilo* sp abunndances in both sprayed (F =1.04; df =3; *P* = 0.24) and unsprayed (F = 0.2; df = 3, 6; *P* = 0.997) fields in rice varieties. Also the abundance of *S. calamistis* was not significant in both sprayed (F = 3.07; df =3, 6; *P* = 0.113) and unsprayed (F = 0.44; df =3, 6; *P* = 0.731) rice fields in rice varieties (Table 4.2).

Table 4.2: Abundance of stem borer species in insecticide treated fields

	Percentage stem borer species (Mean ± SE)			
Rice Variety	***Chilo* sp**		***Sesamia calamistis***	
	un sprayed fields	**Sprayed fields**	**Unsprayed fields**	**Sprayed fields**
SARO5	94.32 ± 2.15a	89.95 ± 0.39a	5.68 ± 2.15b	10.05±0.39a
SUPA	86.31 ± 1.51a	88.35 ± 0.27a	13.69 ± 1.50ab	11.65 ± 0.26a
Mbawa mbili	84.81 ± 2.10a	89.27 ± 0.33a	15.19 ± 2.0a	10.73 ± 0.33a
Lawama	90.62 ± 0.57a	88.33 ± 0.23a	9.38 ± 0.9a	11.67 ± 0.59a
C.V	6.14	3.21	8.2	4.31
P - value	0.44	0.997	0.113	0.731

Means for *Sesamia calamistis* were log transformed prior analysis; values are presented in original scale. Values followed by the same letters in a column are not statistically diffrence (*P* > 0.05) LSD. C. V = Coefficient of variation; SE = standard error.

4.3.3 Species abundance in rice varieties

The two stem borers species were more abundant at reproductive stage than the vegetative stage (Fig. 4.2). Greatest abundance was that of *Chilo* sp which was significantly high in SARO5 variety (F = 2.72; df = 2, 18; *P* = 0.012) during reproductive and vegetative stages of rice growth than SUPA, Mbawa mbili and Lawama). Unlike *Chilo* sp, abundance of *S. calamistis* was significantly high on SUPA variety and least on SARO5 rice variety in both rice growth stages (F = 5.17; df = 2, 18; *P* = 0.017) (Fig. 4.2). SARO5 was highly attracted by *Chilo* sp and SUPA with *S. calamistis.*

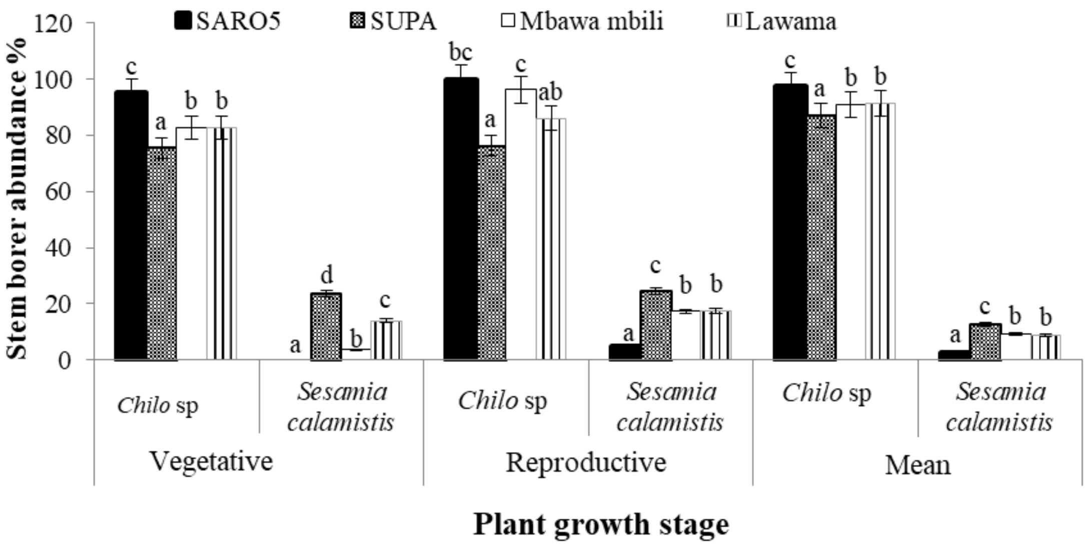


Figure 4. 2: Abundance of stem borer species in varieties

Bars with the same letter are not significantly different at *P* > 0.05 as per Fisher's test of Least significant difference.

4.3.4 Stem borer incidences in wards

The dead heart incidences were higher than white head in both wards (Table 4.3). Among the surveyed wards, Signali and Mkula had more damage incidences than Sanje for both dead heart and white head. There were significant differences in dead heart incidences during vegetative stage among wards (*P* = 0.032) but there was no significant differences in white head incidences during reproductive stage (*P* = 0.42). At vegetative stage, the highest incidence was recorded in Mkula and Signali with the least incidence of in Sanje.

Table 4.3: Stem borer incidences in wards

Ward	Percentage damage (Mean ± SE) Dead heart at vegetative stage	White head at reproductive stage
Signali	8.98 ± 1.56ab	5.24 ± 0.58a
Mkula	9.77 ± 1.62b	5.49 ± 1.41a
Sanje	4.27 ± 1.15a	4.68 ± 0.34a
C. V	1.454	0.89
p - value	0.032	0.42

SE = standard error and C. V = coeffiecient of variation. Values followed by the same letters in a column are not statistically diffrent ($P \geq 0.05$) LSD.

4.3.5 Stem borer incidences in insecticide treated fields

Higher incidences for rice stem borers were recorded at the vegetative stage than the reproductive stage in both sprayed and unsprayed fields. There was no significant differences in white head formation ($P > 0.05$) between rice varieties in sprayed and unsprayed fields except for dead heart formation (F = 5.71; df = 2, 18; $P = 0.028$ for insecticide treated fields; F = 3.72; df = 2, 18; $P = 0.014$ for none insecticide treated fields< 0.05). Rice variety, SARO5, had the highest dead heart incidences for both sprayed and unsprayed fields. All four rice varieties express similar white head incidences levels in both sprayed and unsprayed fields.

Table 4.4: Stem borer's incidences in insecticide treated fields

Rice Variety	Percentage stem borer damage (Mean ± SE)			
	Dead heart at vegetative stage		White head at reproductive stage	
	Sprayed fields	None sprayed fields	Sprayed fields	None sprayed fields
SARO5	7.68 ± 1.49b	12.42 ± 1.49b	5.48 ± 0.94b	6.68 ± 1.04a
SUPA	4.59 ± 0.94a	8.77 ± 1.38a	4.63 ± 0.82ab	5.82 ± 1.14ab
Mbawa mbili	4.75 ± 0.97a	9.74 ± 1.48a	3.63 ± 0.61a	6.88 ± 1.24b
Lawama	3.54 ± 0.67a	7.16 ± 1.12a	3.65 ± 0.68a	4.513 ± 0.60a
C. V	3.14	4.21	2.23	3.31
P - value	0.028	0.014	0.104	0.121

SE = standard error and C. V = coeffiecient of variation. Values followed by the same letters in a column are not statistically different ($P > 0.05$).

4.3.6 Response of rice varieties to stem borer incidence

SARO5 was the most susceptible variety to stem borers' damage with the highest record of dead heart and white head formation followed by SUPA and Mbawambili (Fig. 4.3). Lawama was somehow tolerant to stem borer damage due to its lowest record of dead heart and white head damage incidences. In all varieties, the dead heart incidences were significantly higher than white head incidences (F = 6.72; df = 2, 18; *P* = 0.021).

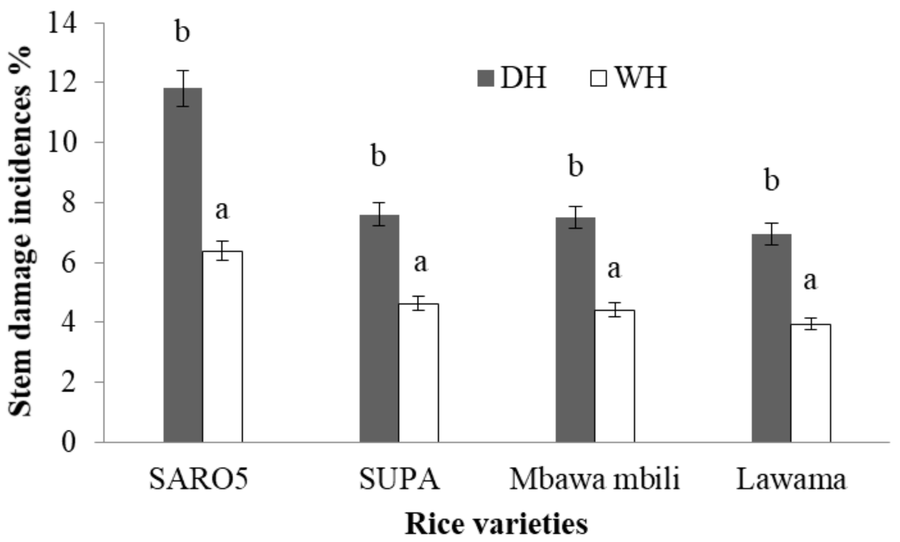


Figure 4.3: Stem borer incidences in rice varieties

DH = dead heart; WH = white head. Bars followed by the same letters are not significantly different (*P* > 0.05) based on Fisher's test of least significant different.

4.4 Discusion

The present study revealed the presence of two stem borer species in Kilombero notably spotted stem borers (*Chilo* sp) and the pink stem borer (*S. calamistis*) in which *Chilo* sp was a dominant and most abundant species in all fields surveyed. The reason for abundance of *Chilo* sp compared to *S. calamistis* may be due to its biological nature of completing life cycle earlier than other stem borer species hence high population build up in a short time. This is supported by the report of Ofomata *et al.* (2000) that *C. partellus* is characterized by colonizing feeding niches considerably earlier than the native stem borers. It outcompetes and decrease the number of other stem borer species that live in similar environment. The findings were also consistent with the study by Nsami *et al.* (2001) who reported that the abundance of *C. partellus* constituted about 80% while *S. calamistis* accounted for only 4% of stem borer species in the Eastern zone of Tanzania. Further report on stem borer by Leonard and Rwegasira (2015) indicated highest abundance of *C. partellus* in rainfed low land rice ecosystem in Kahama district as compared to *M. separatella* and *S. calamistis*.

Abundance of stem borers was observed to be affected by growth stages of rice crop. The highest abundance was recorded during reproductive stage than vegetative stage of rice for the two stem borer species. The causes of such variation may be due to availability of enough food for borers to feed that favoured fast growth and population build up during reproductive stage and less during vegetative stage. This was consistent with the study of Sarwar (2012) who reported that stem borer population build up occurs during flowering stage due to increased rice tillers and large stem diameter that ensures production of better quality food in stems.

Analysis on the influence of rice varieties on stem borer species abundance was statistically significant. The two rice varieties which are SARO5 and SUPA were recorded with highest abundance as compared to Mbawambili and Lawama varieties. The reasons could be due to differences in chemical characteristics of the varieties including aroma as basic attraction to stem borer's damage. The SARO5 and SUPA rice varieties are known to be aromatic according to Kioko *et al.* (2015), the preferred characteristic for stem borers (Sarwar, 2012). Similar observations were made by Sarwar (2011) who reported high stem borer's damage in aromatic varieties than non-aromatic varieties by describing the aroma characteristic as one of the key attraction factor in adult moths for elevated feeding and oviposition. He also argued that there is reduced stem borer longevity, reproduction and increased mortality in non-aromatic varieties due to production of antibiosis chemicals that lowered the population.

The abundance of stem borers and white head damage incidence was not affected by insecticide spray among rice varieties. The reasons could either be development of pest resistance due to continues use of one insecticide in controlling one kind of insect, wrong time of application and the use of incorrect dosage due to lack of knowledge on pesticide use. Control of stem borers using insecticides is sometimes difficult to achieve because the larvae (the destructive stage) and pupa of borers completes their cycles inside the stems. Moreover they have overlapping population in the field which complicates the timing in insecticide application for a successful control (Wale *et al*., 2006).

Historically farmers under the study area used to spray the same insecticide (Lambda cyhalothrin) every season when stem borer damages signs are observed in the fields suggesting the possible development of resistance. This corresponds with the report by Li *et al.* (2011) that a significant and unexpected resistance level was detected in *Sesamia inferens* Walker from Miaoli, Changhua, Chiayi and Tainan counties due to continuous application of Imidacloprid and Clothianidin insecticides. Further, the findings by Sarwar *et al*. (2012) have reported that many farmers rely on the use of insecticides in control of stem borers but most of them are not successful. Likewise, Muralidharan and Pasali (2006) reported insignificant difference between Diazinon and Carbofuran insecticides in reduction of incidences of yellow stem borers at white ear head stage in India.

The insecticides used by farmers in the study area none are systemic and unfortunately the timing of application is also wrong because actions are taken after the damages have been caused when dead heart or white head are observed. Nwilene *et al.* (2008) reported that a good timing for spraying insecticides in managing the borers is 20 days after planting to combat dipteran stem borers and 50 - 70 days after planting in in order to combat Lepidopteron stem borers. Similar findings were by ISU (2012) who suggested that for insecticides to be effective, spraying had to be done before most larvae tunnelled into stalk.

The current study revealed differences in stem borer incidences among wards, rice variety and growth stage of rice. The difference in stem borer damage might be due to rice varieties grown ward and time of damage. SARO5, the variety most grown in Signali and Mkula wards was very susceptible given the greatest stem borer damages. Moreover the most abundant stem borer, *Chilo* sp was plentiful in the two wards. Such scenario could be explained by the observation of Touhidur *et al.* (2002) who reported that the population density, the timing of injury and rice growing conditions were the key factors that favour stem borer damage.

Rice varieties genetic characteristics such as aroma have also implication in stem borer's preferences for damages. Sarwar (2012) reported high stem borer dead heart incidences of 5.44% and white head incidences of 4.75% in Aromatic Basmati-370 and dead heart incidence of 3.21% and white head incidence of 2.47% in none aromatic IR8 rice varieties. The low incidence in none aromatic varieties could be due to production of antixenosis which reduces plant attractiveness and tolerance to stem borer damages (Sarwar *et al.*, 2010). Ogah (2013) suggested that varieties respond differently to stem borer attack hence the differences in stem borer incidences observed among the rice varieties.

Higher incidence was recorded in vegetative than reproduction stage of rice growth. The reason could be the ability of the rice crop to compensate the low per cent incidence during vegetative stage by producing new tillers which sometimes become damaged and increase the incidences with constant incidence during reproduction stage. Muralidharan and Pasalu (2006) reported that low percentage of dead heart tillers can be compensated by producing more tillers at early dead heart damage, where the nodal tillers become light and lead to yield loss of 1% in every 2% dead heart incidence. This was also consistent with the study by Sarwar (2012) who reported the highest stem borers incidences during vegetative stage than in reproduction stage, the reason being the sugar content and phenol content in stem tissues of the crop where the former one is high at maximum tillering stage which favour high larvae incidence and later become high during reproduction stage which favour low larvae incidence.

4.5 Conclusions

The two stem borer species, *Chilo* sp and *Sesamia calamistis* were found to exist in Kilombero rice production schemes of which the former was more abundant than the later. The abundance of stem borer species and damage incidences were varied based on growth stages of rice crop. Damages associated with rice stem borers were similar in insecticide sprayed and non-sprayed fields suggesting the ineffectiveness of the commonly used Lambda cyhalothrin insecticide.

Acknoledgements

This study was supported by USAID Feed the Future IPM Innovation Lab, Virginia Tech, Cooperative Agreement No. AID-OAA-L-15-00001 through International Centre of Insect physiology and Ecology (ICIPE). Thanks are due to farmers and extension officers in the study area for willingly working with us to undertake the study in their farms.

References

Addo-Bediako, A and Thanguane, N. (2012). Stem borer distribution in different sorghum cultivars as influenced by soil fertility. *Agricultural Science Research Journal* 2: 189 – 194.

Banwo, O. O. (2002). Management of Major insect pests of rice in Tanzania. *Plant Protection Science* 38(3): 108 – 113.

Banwo, O. O., Makundi, R. H. Abdallah, R. H and Mbapila, J. C. (2001). Identification of vectors of rice yellow mottle virus in Tanzania. *Plant Protection Science* 33: 395 – 403.

Gomez, K. A and Gomez, A. A. (1984). *Statistical procedures for agricultural research*. 2nd Edition, John Wiley and Sons, New York. 680pp.

Indike, A. (2002). Analysis of pest management methods used for rice stem borer (*Scirpophagaincertulas*) in Sri Lanka based on the concept of Sustainable Development. Thesis for award of Masters Degree at Lund University, Maharagama, Colombo, Sri Lanka. 77pp.

Ismaila, M. (2010). Stem borer infestation on maize plants treated with salicylic acid. Dissertation for Award of Master's Degree at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. 55pp.

ISU (Iowa State University) (2012). *Field crop insects*. Iowa Soy bean association. 4 – 5pp.

Kioko, W. F., M. A. Musyoki, N. M. Piero, K. G. Muriira, N. D. Wavinya, L., Rose, M., F and Ngithi, N. L. (2015. Genetic diversity studies on selected rice (*Oryza sativa* L.) populations based on aroma and cooked kernel elongation. *Journal of Phylogen Evolution Biology* 3: 158.

Leonard, A and Rwegasira, G. M. (2015). Abundance and spatial dispersion of rice stem borer species in Kahama, Tanzania. *Journal of Insect Science* 15(1): 132.

Leonard, A. (2015). Incidences and spatial distribution of stem borers in rice crop in Kahama District. Dissertation, for award of Masters Degree in Crop Science at Sokoine University of Agriculture, Morogoro, Tanzania. 66pp.

Li, C., Cheng, X and Dai, S. (2011). Distribution and Insecticide Resistance of Pink Stem Borer, *Sesamia inferens* (Lepidoptera: Noctuidae), in Taiwan. *Formos Entomology Journal* 31: 39 - 50.

Muralidharan, K and Pasalu, I. C. (2006). Assessments of crop losses in rice ecosystems due to stem borer damage (Lepidoptera: Pyralidae). *Crop Protection* 25: 409 - 417.

Niyibigira, E. I., Abdallah, Z. S., Overholt, W.A., Lada, V. Y and Van Huis, A. (2001). Distribution and abundance of lepidopteran stem borers and associated indigenous parasitoids in maize and soghum in Zanzibar. *Insect Science Aplication* 21(4): 335 - 346.

Nsami, E., Mgoo, V. H and Omwega, C. O. (2001). Distribution and species composition of cereal stem borers in the eastern zone of Tanzania. *Insect Science Application* 4: 347 - 351.

Nwilene, F. E., Sanyang, S., Trao, A. K., Togola, A., Goergen, G and Agunbiade, T. A. (2008). *Rice stem borers: Biology, ecology and control. Field Guide and Technical Manual*. Cotonou, Benin. Africa Rice Centre (Warda). 28pp.

Ofomata, V. C., Overholt, W. A., Lux, S. A., Van Huis, A and Egwuatu, R. I. (2000). Comparative studies on the fecundity, egg survival, larval feeding and development of *Chilo partellus* and *Chilo orichalcociliellus* (Lepidoptera: Cambridae) on five grasses. *Annal of Entomological Science* 3: 492 - 499.

Ogah, E. O. (2013). Evaluating the impact of new rice for Africa (NERICA) in the management of rice stem borers. *Journal of Science International* 1(5): 160 - 166.

Pathak, M and Khan, Z. R. (1994). *Insect pests of rice*. International centre of insect physiology and ecology (ICIPE). International rice research institute (IRRI). Manila Philipins. 5 - 16pp.

Pathak, M. D. (1997). Defense of the rice crop against pests. The genetic basis of epidemics in agriculture. *Annals of Academic Science* 287: 287 - 295.

R version 3.3.1. (2016). The R foundation for statistical computing platform: x86_64-w64-mingw32/x64 (64-bit).

Rahaman, M. M., Islam, K. S., Jahan, M and Mamun, M. A. A. (2014). Relative abundance of stem borer species and natural enemies in rice ecosystem at Madhupur, Tangail, Bangladesh. *Journal of Bangladesh Agricultural University*, 12(2): 267 – 272.

Rami, K., Overholt, W. A., Khan, Z. R and Polaszek, A. (2002). Biology and management of economically important lepidopteran cereal stem borers in Africa. *Annal Revew of Entomology* 47: 701 – 731.

Sarwar, M. (2011). Effects of Zinc fertilizer application on the incidence of rice stem borers (*Scirpophaga*species) (Lepidoptera: Pyralidae) in rice (*Oryza sativa* L.) crop. *Journal of Cereals and Oilseeds* 2(5): 61 - 65.

Sarwar, M. (2012). Management of rice stem borers (Lepidoptera: Pyralidae) through host plant resistance in early, medium and late plantings of rice (*Oryzasativa*L.). *Journal of Cereals and Oil seeds* 3(1): 10 - 14.

Sarwar, M., Ali, A., Ahmad, N and Tofique, N. (2005). *Expediency of different botanical products intended for managing the opulation of rice stem borers*. 25th Pakistan Congress of Zoology, March 1-3. Pakisatan Agricultural University, Tandojam 25: 15 - 23.

Sarwar, M., Ahmad, N., Nasrullah, A and Tofique, M. (2010). Tolerance of different rice genotypes (*Oryzasativa* L.) against the infestation of rice stem borers under natural field conditions. *The Nucleus* 47(3): 253 - 259.

Suresh, K., Bhaskaran, R. K. M., Santhilkumaran, S., Rajaval, M and Shanti, K. (2009). Effect of organic sources of nutrient on management of sucking pest of *Cassia angustifolia*. *Journal Plant Protection Science* 17: 32 - 36.

Touhidur, R., Khalequzzaman, M and Ataur, M. R. K. (2004). Assessment of infestation and yield loss by stem borers on aromatic variety of rice. *Journal of Asia-Pacific Entomology* 7(1): 89 - 95.

Wale, M., Schulthess, F., Kairu, E. W and Omwega, C. O. (2006). Cereal yield losses caused by lepidopteron stem borers at different nitrogen fertilizer rates in Ethiopia. *Journal of Applied Entomology* 130(4): 220 - 229.

CHAPTER FIVE

5.0 EFFICACY OF SELECTED BIOPESTICIDES AND BOTANICAL EXTRACTS IN MANAGING RICE STEM BORER, *Chilo partellus* (Swinhoe) (LEPIDOPTERA: CRAMBIDAE) IN TANZANIA

Published in Journal of Agriculture and Ecology Research International 15(4): 1-16. doi: 10.9734/JAERI/2018/44015

Abstract

Stem borers have been reported as most injurious insect pests of rice among the insects that attack rice crop globally. The attempts to control insects have changed over time from chemicals to natural control methods. This study was therefore aimed at evaluating the efficacy of fungi based biopesticides and botanical extracts in the control of rice stem borers. The experiment was conducted under controlled environment (in laboratory and in screen house) at Sokoine University of Agriculture by artificial infestation using first instar larvae of *Chilo partellus*. The experiments involved six treatments which included two commercial fungi based biopesticides (*Beauveria bassiana* and *Metarhizium anisopliae*), two botanical extracts (*Neorautanenia mitis* and *Derris eliptica*), one of the currently recommended synthetic insecticide, Amekan 344EC (Cypermethrin 144g/l + Imidacloprid 200 g/l), and untreated control (distilled water). Stem borer mortality due to fungi based biopesticides and botanical extracts ranged from 58% to 78% slightly lower than that of Amekan 344EC (positive control) which was 94% under laboratory conditions. Results from screen house experiments (when compared with the negative control) indicated a significant ($P < 0.05$) reduction of *C. partellus* damage incidences by 60.62% and 70.70% for dead heart and white head respectively when *M. anisopliae* was used while 61.86% and 51.17% dead hearts and white head respectively were attained with *B. bassiana. Neorautanenia mitis* reduced dead heart and white heads by 53.14% and 49.28% respectively whereas 45% and 42.01% reduction in dead heart and white head respectively were attained when *D. elliptica* was applied. Comparison of rice yield attained using Amekan 344EC (treated control) to control stem borer suggested percentage reduction of yield losses by 89.31% using *M. anisopliae*; 80.3% using *B. bassiana*; 72.42% using *N. mitis* and 67.77% using *D. elliptica*. Grain yield ranging from 4.84 to 6.39 t ha^{-1} recorded in either botanical or fungi based biopesticides treated plots was higher than 2.84 t ha-^{1} recorded in un-treated (negative) control plots. The study therefore indicated the possibility of controlling rice stem borers using the two fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and botanical extracts (*N. mitis* and *D. elliptica*).

Keywords: Botanical extracts, damage incidences; fungi based biopesticides, management, stem borer, yield loss

5.1 Introduction

Rice (*Oryza sativa* L) one of the major cereal crops in the world is attacked by various insect pests where Lepidopteran stem borers has been reported as the most injurious (Sarwar, 2012). About 21 Lepidopteran stem borers have been reported as economically important insect pests of cultivated grasses in Africa including 12 Crambids, 7 Noctuids and 2 Pyralids in which 7 of them are pests of rice crop (Kfir *et al.*, 2002). Rice stem borers in Africa were primarily reported in West Africa in 1984 in areas where rice crop was cultivated as an important food crop. Four stem borers were reported which includes; African white borer (*Maliarpha separatella* Ragot) (Lepidoptera: Pyralidae), African yellow stem borers (*Scirpophaga* spp.) (Lepidoptera: Pyralidae), African stripped stem borers (*Chilo* spp.) (Lepidoptera: Pyralidae) and pink stem borers (*Sesamia* spp.)

(Lepidoptera: Noctuidae) all of African origin except for *M. separatella* which originated in Asia (Nwilene *et al*., 2009).

In East Africa, at least one species of each genus have been reported. These includes *Maliarpha Separatella* Ragot, *Sesamia calamistis* Hampson and *Chilo partellus* Swinhoe in Tanzania (Banwo, 2002; Leonard and Rwegasira, 2015; January *et al*., 2018), *C. partellus, M. separatella and S. calamistis* in Kenya (WARDA, 2007; Mailafiya *et al*., 2010) and *Chilo* spp in Uganda (Harris, 1990). Yield losses due to stem borers are attributed to their progressive feeding at larvae stage, which had a tunnelling effect in a stem. When larvae enters the stem, it causes several destructions in plant including damage on growing point, early leaf senescence, interference with metabolite and nutrient translocation which results to stunting of plant, stem breakage, lodging and grain deformity and altimetry yield loss (Bosque-P´erez and Mareck,1991; Kfir *et al*., 2002). Different loss estimates are expected in relation to crop type, country where the crop is cultivated and stem borer species. Estimated yield losses due to *C. partellus* in sorghum crop exceed 50% and 70% in maize in Zimbabwe (SeshuReddy, 1988). In Tanzania, maize grain yield loss due to *C. partellus* of up to 53% has been reported (Mgoo *et al*., 2006). For rice crop, grain yield loss of up to 54% due to African striped borer have been reported in Nigeria (Ukwungwu and Odebiyi, 2008) and up to 100% due to yellow stem borers have been reported in Kenya, a neighbouring country with the same climatic condition like Tanzania (Kega *et al*., 2016).

Management of stem borers has been relied on the use of synthetic insecticides, but has been ineffective technique due to cryptic nature of stem borer attack, disruption of environment and unaffordability to purchase insecticides by small scale farmers (Ogah *et al*., 2011; Prasad and Gupta, 2012). The attempts to control insects have changed over time from chemicals to natural control methods (Shahid *et al.*, 2016)**.** Of the various natural control methods, biopesticides (Teshome and Tefera, 2009) and botanical extracts (Mulungu *et al.*, 2011) have received considerable attentions as a viable alternative to chemical pesticides. When these natural methods are used in place of conventional insecticides they can minimize environmental pollution, preserve non-target organisms such as natural enemies and delay insecticide induced pest resistance (Ogah *et al.*, 2011).

The study by Shahid *et al*. (2009) reported a mass reduction of stem borers and rice folders in their laboratory experiment using bio pesticides based products like fungus *Metarhizium anisopliae* (Metsch.) Sorokin and bacteria *Bacillus thuringiensis* Berliner (Bt). Also Teshome and Tefera, (2009) have reported *M*. *anisopliae* and *Beauveria bassiana* (Balls.) Vull isolates as the most virulent biopesticides causing 84.4% to 98.3% mortality to maize weevil (*Sitophilus zeamais* Motschulsky) when tested in laboratory. Further the study by (Tefera and Pringle, 2007) testifies the suppression of foliar damage, reduction of stem tunnelling and dead heart when conidial suspension of *M*. *anisopliae* and *B. bassiana* isolates was sprayed onto 3 to 4-week-old maize plants infested with larvae of *C. partellus* in screen house. The use of biopesticides will benefit rice farmers; nevertheless, the efficacy of *M*. *anisopliae* and *B. bassiana* for rice stem borers control has not been reported. The fungi can affect the insect through contact with the insect's body (Hailu *et al*., 2012). As the fungi adhere to the insect cuticle it germinates and form appressorium. The appressorium will penetrates the insect body and colonize the hymolymph. Appressorium will extrudes and sporulate inside the haemolymph which finally kill the insect (Manisegaran *et al*., 2011).

The use of botanical extracts in management of insect pests as an alternative to synthetic insecticides have been reported in crop protection for many centuries (Prakash *et al*.,

2008) but their potentials have not been fully evaluated. Some popular botanical extracts such as neem plant (*Azadirachta indica* Juss), garlic (*Allium sativum* L.) and ginger (*Zingiber officinale* Roscoe) have been used in the management of post-flowering insect pests in Nigeria (Ogah *et al*., 2013). Neem oil from neem plant has been reported by Islam *et al*. (2013) as potential control measures against yellow stem borer damages in rice crop. On the other hand, Mulungu *et al*. (2007) have reported the potential of Nyongwe plant (*Neorautanenia mitis* (A. Rich.) Verdic) in controlling bean bruchid (*Zabrotes subfasciatus* Boh) whereas Muro (2010) has reported an increase in mortality of melon fly (*Bactocera cucurbitae* Concuillet) when using Derris plant (*Derris elliptica* (Wall.) Beth extracts). Among the five botanicals, extracts from *D. elliptica* and *N. mittis* were tested in the current study. The bioactive compounds of *D. elliptica* are rotenone, derrid, anhydroderrid, derrin, tubotoxin, and tubain (Visetson and Milne, 2001; Zubairi *et al*., 2014) while that of of *N. mittis* includes rautandiol, neoduline, neotenone, pachyrrhizine and 12a-hydroxylrotenone (Lasisi and Adesomoju, 2015). The mode of action of these botanicals includes repellent action through contact as insect ingest or attempting to feed on the crop leaves and for their larvae picking up the residues sprayed on leaves during spray or through foraging behaviour which ultimately suffer through feeding inhibition, or stomach poison effect which will result into death of the insect as it feeds on the residues sprayed on leaves (Ogah *et al*., 2011). The potential of these effective botanicals in controlling the rice stem borers were not reported priour to this study. The current study reports on the efficacy of two commercial fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and water extracts of two botanicals (*N. mitis* and *D. elliptica*) in the control of rice stem borer.

5.2 Materials and Methods

5.2.1 Description of the study site

The study was conducted in Laboratory and in screen house under artificial infestation at Sokoine University of Agriculture in Morogoro region located at Latitudes $6^0$56'S, Longitudes $35^0$37'E and Altitude of 525 m.a.s.l. between March 2017 and January 2018.

5.2.2 Treatments

The experiment involved four treatments and two controls. The treatments include: two commercial fungi based biopesticides (*B. bassiana* and *M. anisopliae)*, obtained from the Real IPM company (Arusha) and two botanicals (*N. mitis)* collected from Makambako and (*D. elliptica*) collected from Handen Tanga. The synthetic insecticide, Amekan 344EC (Cypermethrin 144g/l + Imidacloprid 200 g/l), one of the currently recommended insecticide, purchased from local Agro-vet shop in Morogoro, Tanzania was used as a positive control (treated control) while untreated control which received neither fungi based biopesticides, botanical extracts nor insecticide was served as negative control.

5.2.3 Preparation of botanical extracts

Fresh roots of *D. elliptica* and *N. mitis* were washed with running tape water to remove soil materials and rinsed with sterile distilled water (SDW) three times. Samples were then chopped into small pieces and placed on benches at room temperature and allowed to dry for three weeks (Akibonde and Ikotum, 2008). The dried materials of each plant species were made into powder separately using grinding machine at Animal Science Department laboratory of Sokoine University of Agriculture, then sieved with 1 mm sieve. The powder of plant material was then packed separately in water proof plastic bags well labelled and stored at temperature of 4^0C until used (Hasan *et al.*, 2005). Crude plant extracts were obtained by infusing 50 g of plant material in 100 ml sterile distilled water (SDW) to give

50% w/v in a 500 ml conical flask and the mixture kept at 25^0C - 28^0C for 20 hours (Nduagu *et al*., 2005). The infusion was then filtered separately through sterile double-layered cheese cloth into a sterile 400 ml beaker and the resulting stock solution collected ready for use (Nduagu *et al*., 2005). A solution of bar soap obtained by dissolving 50 g in 250 ml of distilled water was also prepared to be used as sticker (Opareke *et al*., 2005). The solutions were used within the same day to avoid degradation of chemical ingredients.

5.2.4 Preparation of microbial and synthetic insecticides

The commercial fungi based biopesticides and synthetic insecticide were prepared following manufacturers recommendation shown on label. The recommendation rates for *M. anisopliae* and *B. bassiana* was 1 ml/l where as that of synthetic insecticide (Amekan 344EC) was 0.25 ml/l. These were prepared and used the same day of preparation.

5.3 Bioassays

An experiment was conducted in Entomology Laboratory at Sokoine University of Agriculture aimed at evaluating the effectiveness of two commercial fungi based biopesticides (*M. anisopliae and B. bassiana*), two botanical extracts (*N. mitis* and *D. elliptica*), one synthetic insecticide, Amekan 344 EC (Cypermethrin 144 g/l + immidacloprid 200 g/l) which save as positive control and one untreated control (distilled water) which saved as negative control.

5.3.1 Insect colony

Egg mass of *C. partellus* initially collected from insectary unit of the International Centre of Insect Physiology and Ecology (ICIPE) were placed in plastic containers with perforated lids at the top, lined with moist tissue paper inside and incubated at 28^0C temperature at Sokoine University Laboratory for two days to allow hatching. The first instar larvae were then reared on an artificial diet according to Tefera *et al*. (2011) method. The composition of the diet was, common bean powder 650 g, brewer's yeast 43 g, glucose 50 g, methyl paraben 8.5 g, ascorbic acid 11 g, sorbic acid 6 g, 3000 ml distilled water, 57 g of agar technology and 12.5 ml of formaldehyde. About 500 larvae were maintained on 250 g diet in a plastic bottle (5 cm x 11 cm). The plastic bottles containing the larvae in diet were then covered with perforated lids at the top and placed on benches at Sokoine University of Agriculture, Entomology Laboratory at room temperature for larvae to grow. The newly molted third instar larvae were fed with pieces of rice stem for 3 days before treatment application for them to become used to the natural conditions (Tefera, 2004).

5.3.2 Treatment application

Thirty third-instar *C. partellus* larvae were placed in 9 cm diameter Petri dishes with perforated lids at the top, lined with moist tissue paper inside. The larvae were treated with three mills of each treatment using laboratory spray tower. The larvae in untreated controls were sprayed with three mils of distilled water only. Petri dishes containing treated and control insects were sealed with masking tape and incubated at 25°C ± 1°C. All treatments and their controls were replicated four times arranged in a completely randomized design. The treated insects and controls were provided with pieces of rice stem daily after frass and debris had been removed. The whole experiment was repeated in seven batches.

5.3.3 Data collection

The mortality was recorded every day from each petridishes contained treated and controls for seven days in such a way that every batch was recorded and discarded once every day for every treatment. Mortality data were corrected for control mortality according to (Abbott, 1925) as follows;

$$\text{Corrected mortality \%} = \left(1 - \frac{\text{n in T after treatment}}{\text{n in CO after treatment}}\right) \text{x100} \qquad \text{………………… (vii)}$$

Where; n = insect population, T = treatment, CO = control

5.4 Screen house experiment

5.4.1 Rice planting

The rice variety TXD 306 (a low land variety which is commonly grown by many farmers and susceptible to stem borers) was used. The experiment was laid out in a randomized complete block design (RCBD) with four replications. The total experimental area in the screen house was 180m^2 (18 m x10 m) with treatment plots measured 4 m^2 (2 m x 2 m). Each treatment plots was partitioned using 0.25 m bunds. The separating distance between blocks and experimental plots was 0.5 m and 0.2 m respectively. Dibbling of seeds was done at two seeds per hole and later thinned to one seedling per hill at 14 days after planting. All necessary field management practice such as weeding and fertilizer were done as required. Fertilizers with nitrogen (N) in form of UREA, Phosphoras (P) in form of Triple supper phosphate and Potassium (K) in form of Muriate of potash (MOP) were applied at the rate of 80:40:40 as described by (Mghase *et al.*, 2010).

5.4.2 Infestation of rice with stem borers

Egg mass of *C. Partellus* was collected from insectary unit of the International Centre of Insect Physiology and Ecology (ICIPE), Kenya. The eggs masses were then placed in plastic containers with perforated lids at the top lined with moist tissue paper inside and incubated at 28^0C temperature at Sokoine University Laboratory for two days to allow hatching prior seedling infestation. Using camel hair brush, each individual plant seedling of about 21 days old from each treatment plots were infested with 10 neonate larvae of *C. partellus.* Infestation of plants were repeated 35 days after planting (two week after first infestation) to ensure sufficient damages of plants in all treatments. Infested plants were left for about three days prior spraying to allow the insects to settle to natural condition (Tefera, 2004).

5.4.3 Treatment application

Each botanical extracts (*N. mitis* and *D. elliptica*) were applied at the rate of 20 ml/l which includes 10 ml of crude plant extract and 10 ml of sticker material (bar soap solution). The dosage was chosen based on (Khan *et al.*, 2013; Majlish *et al.*, 2015) reports on preparation of botanicals extracts for insect pest control. The two biopesticides (*M. anisopliae* and *B. bassiana* were applied at the rate of 1 ml/l and that of synthetic insecticide at the rate of 0.25 ml/l which were both according to the recommendations on label as per manufacturers.

A hand sprayer of about two litre in volume was used. Sprayer calibration was done to determine the amount of solution required to cover the treatment area by filling the sprayer with water and spray an area of 4 m^2 which was equivalent to treatment area. The amount of water required to cover the entire treatment area was measured and the time recorded. About half a litre was enough to cover the entire treatment area. This amount of spray was again retested to the same area to find out the amount of spray which remains in the sprayer after spraying. The remaining amount was measured and added as additional to the half a litre of each treatment during application. The nozzle was adjusted accordingly to avoid wastage of chemicals. Spraying was done thrice (3, 21 and 42 days after infestation) to the respective treatment plots except untreated control which was sprayed with water and sticker solution only. Spraying was done by targeting on run off points of the leaves.

The daily temperature and relative humidity (RH) in the screen house was recorded throughout the experimental period. The mean temperature and RH recorded was ranged from 20^0C – 31^0C and 60% respectively. The Temperature and RH were suitable for fungal and insect growth and disease development (Mishra *et al*., 2015).

5.4.4 Data collection

Data for growth parameters (plant height and number of tillers per hill for both infested and un-infested) was taken during mid-grain filling stage of rice crop in a 1 m^2 area sampled in every treatment plot. Plant height was measured as the distance from the soil level to the base of the flag leaf using ruler. At harvest, number of panicles and number of white heads were counted. Harvesting was done in every treatment plots from 1 m^2 sampled areas for infested hills and un-infested hills separately for easy estimation of yield losses. Grain yield (t ha^{-1}) was calculated based on the harvested unit area at 14% moisture content. The incidence was calculated using formula as described by Suresh *et al.* (2009) as follows;

$$\text{Stem borer incidence \%} = \frac{\text{Number of dead hearts or white heads}}{\text{Total number of productive tillers}} \text{X100} \quad \text{...... (viii)}$$

Percentage increase or reduction in damage incidences were calculated using the formula;

$$I = \frac{A - B}{A} \text{X100} \quad \text{.. (ix)}$$

control treatment and B = Incidence of individual treatment.

The yield losses were also estimated out of yield obtained by using the method of (Rahman *et al.*, 2004);

$$L = \frac{YP - YO}{YP} \text{X100} \quad \text{.. (x)}$$

Where; L = percentage yield loss due to borer, YP = Yield per m^2 based solely on un-infested plants in the sampling area and Yo = Yield per m^2 based on both infested and non-infested plants in the sampling area. Percentage data were tested for normality and found not normally distributed and therefore arcsine transformed prior to analysis.

5.4.1 Data analysis

The collected data were subjected to R statistical software for analysis. Significant differences among means were separated using the Student Newman Keuls (SNK) at 95% confidence interval. The analysis model was according to Gomez and Gomez (1984) for RCBD i.e $Y_{ij} = \mu + T_i + \beta_j + E_{ij}$; where Y_{ij} = Response, μ= mean, T_i is the i^{th} treatment effect, β_j is the j^{th} Replication effect, and E_{ij} is the random error of the observation. Regression analysis were performed using excel to see the relationship between damage incidences and rice grain yield.

5.5 Results

5.5.1 Effects of treatments on stem borer mortality

There were significant differences in mean mortality ($F = 5.18$; df = 5, 15; $P < 0.001$) of stem borers (*C. partellus*) treated with different botanical extracts and fungi based biopesticides (Table 5.1). The use of fungi based biopesticides and botanical extracts led to slightly lower stem borer mortality that ranged from 58% to 78% compared to 94% due to Amekan 344EC (positive control).

Table 5.1: Effect of treatments on stem borer mortality

	Mortality rates (%) in different days (Mean ± SE)							
Treatments	**Day 1**	**Day 2**	**DAY 3**	**DAY 4**	**DAY 5**	**DAY 6**	**Day 7**	**Mean ± SE**
Untreated (control)	0 ± 0.00a	0 ± 0.00a	0 ±0.00a	0 ± 0.00a	0 ± 0.00a	0 ± 0.00a	0 ± 0.00a	0 ± 0.00a
D. elliptica	35 ± 6.58b	39 ± 8.48b	50.4 ± 6.71b	46 ± 8.487b	74 ± 4.19b	78 ±3.69b	80 ± 3.53b	58 ± 5.43b
N. mitis	41 ± 6.75bc	45 ± 8.39b	60.41 ± 5.81bc	55 ± 7.44bc	86 ± 2.55c	94 ± 1.31c	95 ± 1.02c	68 ± 4.54c
B. bassiana	42 ± 7.49bc	53 ± 8.344c	68.33 ± 5.29c	70 ± 5.73cd	91 ± 1.87cd	95 ± 1.18c	100 ± 0.00c	74 ± 4.32cd
M. anisopliae	47 ± 8.37c	62 ± 8.66d	76.31 ± 5.02c	82 ± 4.62cd	97 ± 0.87d	100 ± 0.24c	100 ± 0.00c	78 ± 4.62d
Amekan 344EC	76 ± 4.61d	92 ± 0.58e	93.71 ± 1.07d	98 ± 2.32d	100 ± 0.00d	100 ± 0.00c	100 ± 0.00c	94 ± 1.44e
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.002	< 0.001	< 0.001	< 0.001
C.V	5.8	5	15.9	23.5	5.1	3.3	4.9	9.07

SE = standard error, C. V = Coeffient of variation. Means followed by the same letters within a column are not significantly different ($P >$ 0.05) using Student Newman Keuls (SNK). Data were arcsine transformed prior to analysis. Presented data are original mean values.

5.5.2 Effects of treatments on rice growth and incidence of stem borers

The fungi based biopesticides and botanical extracts application had a significant (*P* < 0.001) effect on plant height, dead heart (DH) and white head (WH) incidences (Table 5.2; Appendix 2). Plots with high pest incidences had shorter plant and reduced number of tillers. There were no significance difference in plant height on plots treated with Amekan 344EC and *M. anisopliae* (*P* > 0.05). These plots had taller plants than height measured in other treatments. Shorter plants were observed in plots treated with *D. elliptica* and untreated control.

Table 5.2: Effects of treatments on rice growth and incidences of stem borers

Treatment	Dosage	Height(cm) (Mean ± SE)	No. Tillers (Mean±SE)	DH % (Mean±SE)	WH% (Mean±SE)
Amekan 344EC	0.25mil/L	130 ± 2.22c	5 ± 0.56a	4.02 ± 2.63a	1.2± 2.48a
M. anisopliae	1mil/L	125 ± 1.46bc	6 ± 0.48a	4.17 ± 2.87a	1.1 ± 2.39a
B. bassiana	1mil/L	123 ± 1.308b	6 ± 0.55a	4.11 ± 3.33a	3 ± 2.66ab
N. mitis	10mil/L	119 ± 1.08ab	7 ± 0.63a	5.01 ± 3.89a	4.05 ± 3.19b
D. elliptica	10mil/L	118 ± 1.45a	6 ± 0.88a	4 ± 4.73a	3.06 ± 4.09ab
Control (Untreated)		115 ± 2.51a	9 ± 1.0a	20.4 ± 2.5b	17 ± 4.5c
P -value		< 0.001	0.434	0.003	< 0.001
C.V		1.5	11.3	22.1	14.1

SE= standard error, C. V= Coeffient of variation, DH = dead heart, WH = white head. Means followed by the same letters within column are not significantly different (*P* > 0.05) using Student Newman Keuls (SNK).

5.5.3 Effects of treatments on reduction of dead heart and white head damages

The incidence of 20% DH observed in untreated control were significantly (*P* < 0.001) higher that 4 to 5% in other treatments. The percentage incidence of 17% WH was in untreated plots. The incidence was higher than 1 to 4% observed in plots treated with fungi based biopesticides, botanical extracts and Amekan 344EC. However, the efficacy of these treatments varied significantly (*P* < 0.05). Application of Amekan 344EC and *M. anissopliae* were more effectively in reducing the incidence of WH than others (Table 5.3; Appendix 2). The percentage reduction of dead heart and white head damage were respectively ranged from 45 – 64 % and 42.01 - 76.19 % as compared to the negative control.

Table 5.3: Effects of treatments on reduction of dead heart and white head damages

Treatment	Dosage	% < DHD ± SE	%<WHD ± SE
Amekan 344EC	0.25mil/L	-64.28 ± 2.36a	-76.19 ± 2.48b
M. anisopliae	1mil/L	-60.62 ± 2.44a	-70.70 ± 2.63b
B. bassiana	1mil/L	-61.86 ± 2.69a	-51.17 ± 3.44a
N.mitis	10mil/L	-53.14 ± 3.34a	-49.28 ± 3.85a
D. elliptica	10mil/L	-45.00 ± 4.22a	-42.01 ± 4.54a
Control (Untreated)		+100 ± 0.0b	+100 ± 0.0c
P-value		< 0.001	< 0.001
C.V		26.4	6

DHD = dead heart damage, WHD = White head damage, SE= standard error and C. V = Coeffient of variation. % Reduction / increase of DHD or WHD were calculated using the Control mean data of Dead heart or White Head as 100% incidence. Negative sign (-) indicate % of reduction while positive sign (+) indicate % of increase in dead heart or white head. Data were arcsine transformed prior to analysis. Presented data are original values.Means followed by the same letters within column are not significantly different (*P* > 0.05) using Student Newman Keuls (SNK).

5.5.4 Effect of tested treatments on rice yield components

The effects of botanical extracts and fungi based biopesticides on rice yield and yielding component are respectively summarised in figure 5.1 and Table 5.4. Significant variation in panicles/m^2 and number of white heads/m^2 were observed among different treatments ($P < 0.01$) except for 1000 grain weight which was insignificant ($P = 0.165$). The number of panicles varied significantly ($P < 0.001$) among treatments (Table 5.4; Appendix 2). Plots treated with Amekan 344EC and *M. anisopliae* had many panicles than the others. Except control, other plots had an average number of panicles that ranged from 137 to 158. These plots had smaller number of white heads incidences than in untreated control.

Table 5.4: Effects of on rice yielding components

Treatment	Dosage	Panicles/m^2	White heads/m^2	1000 grain weight(g)
Control (Untreated)	-	119 ± 9.65a	33.5 ± 4.68d	28.07 ± 0.21a
Deris elliptica	10mil/L	137 ± 7.43ab	7.5 ± 0.80c	28.98 ± 0.15ab
Neorautanenia mitis	10mil/L	153 ± 5.82bc	5.25 ± 0.80abc	28.63 ± 0.18a
Beauveria bassiana	1mil/L	158 ± 5.41bc	5.75 ± 0.98bc	28.9 ± 0.17ab
Metarhizium anisopliae	1mil/L	172.2 ± 3.55cd	2.75 ± 1.37ab	28.88 ± 0.22ab
Amekan 344EC	0.25mil/L	184.5 ± 8.92d	7.5 ± 1.15a	29.63 ± 1.34b
P - value		< 0.001	< 0.001	0.165
C.V		2.1	11.5	12.4

SE = standard error, C. V= Coeffient of variation. Means followed by the same letters within column are not significantly different ($P > 0.05$) using Student Newman Keuls (SNK).

5.5.5 Effects of tested stem borer control techniques on rice grain yield

Rice grain yield in botanical extracts, Amekan 344EC and fungi based biopesticides treated plots differed significantly ($P < 0.001$) (Fig. 5.1). Grain yield ranging from 4.837 – 6.387 t ha^{-1} recorded in either botanical or fungi based biopesticides treated plots were higher than 2.837t/ha recorded in un-treated control plots. Yield potential were in order of Amekan 344EC (t ha^{-1}) > *M. anisopliae* (t ha^{-1}) >*B. bassiana* (t h^{-1}) > *N. mitis* (t ha^{-1}) > *D. elliptica* > Control (t ha^{-1}).

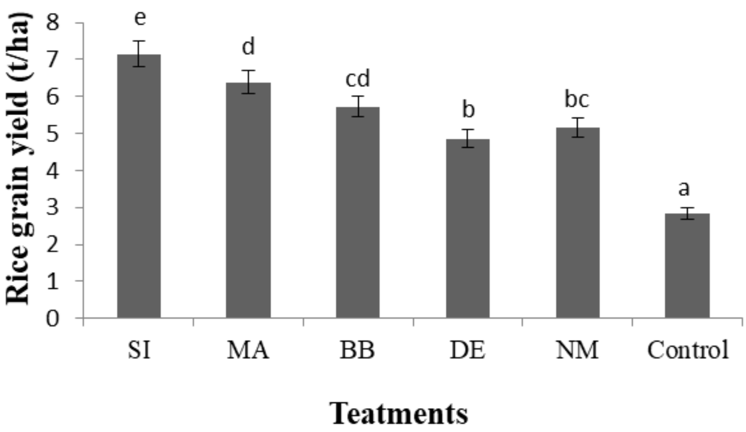
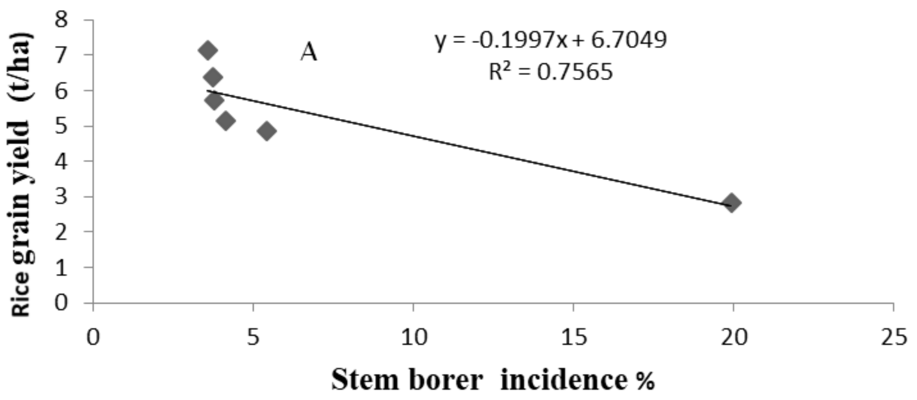


Figure 5.1: Effects of stem borer control techniques on rice grain yield

SI = synthetic insecticide (Amekan 344EC), MA = *Metarhizium anisopliae*, BB = *Beauveria bassiana*, DE = *Derris elliptica*, NM = *Neorautanenia mitis.* Means followed by the same letters are not significantly different ($P > 0.05$) using Student Newman Keuls (SNK).

5.5.6 Relationship between incidences, grain yield and 100 grain weight

Figure 5.2 and 5.3 summarises the relationship between rice stem borer damage incidences, rice grain yield and 1000 grain weight in plots with and without control measures. Grain yield and 1000 seed weight had a significant negative relationship with stem borer damage incidences. Their negative association was confirmed by low grain yield and 1000 seed weight in plots with greater dead heart and white head incidences, which had a significant contribution on grain weight reduction.



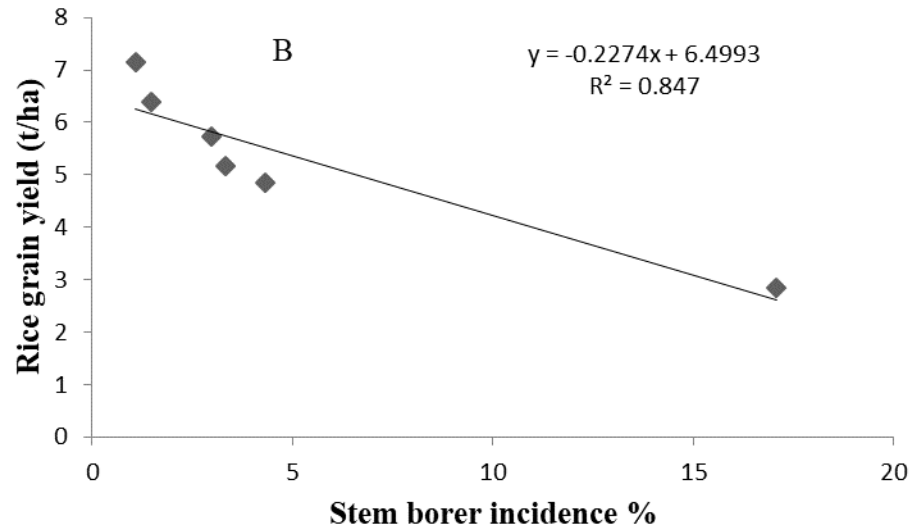
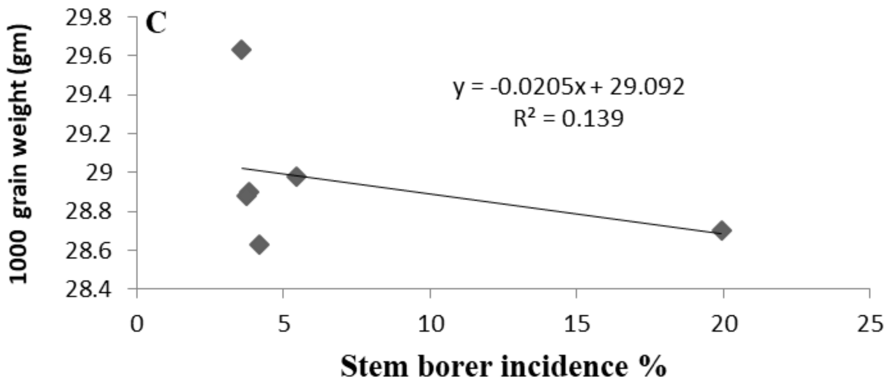


Figure 5.2: Relationship between stem borer incidences and rice grain yield

The six star dots represent six treatments (Amekan 344EC, *D. elliptica*, *N. mitis*, *M. anisopliae*, *B. bassiana* and Control). Letters A and B represents stem borer incidences at vegetative and reproduction stage of rice growth respectively.



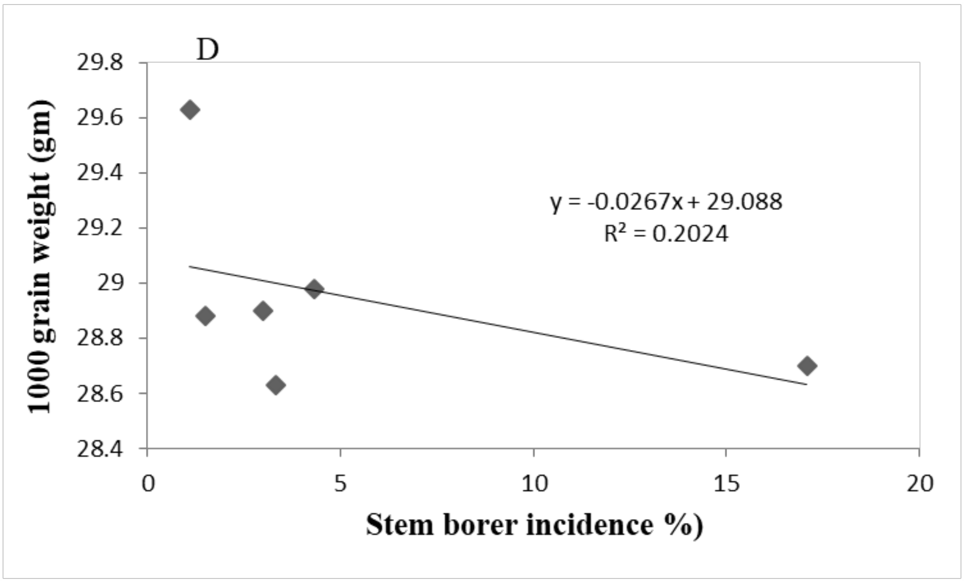


Figure 5.3: **Relationship between stem borer incidences and 1000 grain weight**

The six star dots represent six treatments (Amekan 344EC, *D. elliptica*, *N. mitis*, *M. anisopliae*, *B. bassiana* and Control). Letters C and D represents stem borer incidences at vegetative and reproduction stage of rice growth respectively.

5.5.7 Effects of tested borer control techniques on rice yield loss

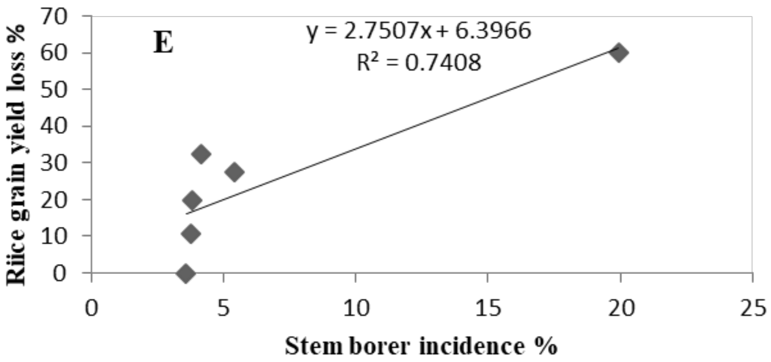
There was a significance differences in yield loss due to *C. partellus* in plots treated with different fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and botanical extracts (*N. mitis* and *D. elliptica*) as compared to their untreated control (P < 0.001) (Table 5.5;

Appendix 2). The yield loss due to *C. partelus* in fungi based biopesticides and botanical extracts ranged from 19.7% - 32.23%. This was lower than 60% recorded from untreated control. Plots treated with *B. bassiana* recorded the lowest yield loss followed by *M. anisopliae, N. mitis* and *D. elliptica* in comparable with untreated control. The regression analysis shows a positive relationship between yield loss and stem borer damage. Increase in dead heart or white head damage incidences leads to an increase in yield loss (Fig. 5.4).

Table 5.5: Effect of treatments on rice yield loss

Treatment	**Dosage**	**Yield loss % (Mean± SE)**
Control (Untreated)		60.01 ± 8.45e
Deris elliptica	10mil/l	32.23 ± 5.3d
Neorautanenia mitis	10mil/l	27.58 ± 4.85cd
Beauveria bassiana	1mil/l	19.70 ± 4.41c
Metarhizium anisopliae	1mil/l	10.69 ± 3.78b
Amekan 344EC	0.25mil/l	0.00 ± 0.0a
P - value		< 0.001
C.V		12.4

SE = standard error, C.V = coeffiecient of variation. Yield loss was calculated based on yield of synthetic pesticide Amekan 344EC (Cypermethrin+immidacloprid) which was a treated control. Data were arcsine transformed prior to analysis. Presented data are original values. Means followed by the same letters within column are not significantly different ($P > 0.05$) based on Student Newman Keuls (SNK).



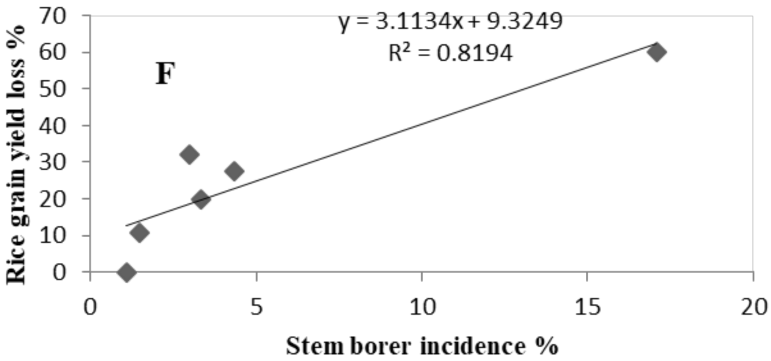


Figure 5.4: Relationship between stem borer incidences and rice yield loss

The six star dots represent six treatments (Amekan 344EC, *D. elliptica*, *N. mitis*, *M. anisopliae*, *B. bassiana* and Control). Letters E and F represents stem borer incidences at vegetative and reproduction stage of rice growth respectively.

5.6 Discussion

The findings of this study exhibited an impressive effectiveness of fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and botanical extracts (*N. mitis* and *D. elliptica*) in reduction of stem borer incidences as compared to the untreated control. This provides evidences for the potentiality of using these biopesticides and botanical extracts in controlling stem borers. Similar findings were reported by Akinsola and Agyen-Sampon (1984) on the efficacy of two microbial biopesticides (*B. bassiana* and *B. thuringinensis*) and extracts of *Azadirachta indica* whereby rice yellow stem borer (*Scirpophaga incertulas* Walker) dead heart incidence were reduced by 57.3 – 62% using *B. bassiana or B. thuringinensis* and 3.48 - 4.44% by using *A. indica* extracts.

Significant influence of stem borer damage incidences on plant height and number of productive tillers per plant in different treatment indicated the variation in efficacy of these treatments in pest management. Reduction of plant height and number of tillers in treatments with higher infestations was attributed to the interference of this pest on both metabolic activity and physiology of the plant. The pest was found to feed on the inner part of the stem and thus interfering with nutrients uptake, water movement and photosynthesis. The influence of stem borer infestations on the reduction of plant height recorded in the current study is in line with the findings by Chatterjee and Mondal, (2014) and Kega *et al*. (2017). Their studies reported plant height reduction due to *M. separatella* feeding at tillering stage of rice crop. The current study observed further that the number of tillers increased as stem borer infestation rates increased suggesting a possible compensatory growth of the rice crop to stem borer infestation at the early stages of growth. This agrees with the findings by Van Den Berg, (1990) and Sylvain (2015) in which more stem borer attack resulted into formation of additional tillers. Further, the study by Kega *et al*. (2016) suggested that enhanced plant compensatory growth mechanism in response to stem borer's damage may be better approach for management of stem borer than using insecticide. Thus, varieties with such behaviour should be encouraged.

Fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and botanical extracts (*N. mitis* and *D. elliptica*) were found to possess a lethal effect that can be used in control of rice stem borers. The comparable but significantly higher grain yield produced by the treated than un-treated control showed that fungi based biopesticides controlled rice stem borers as efficiently as chemical insecticides. The findings are consistent with the study by Akinsola and Agyen-Sampong (1984) who reported an increase in rice yield using bio rational insecticide like *M. anisopliae*, *B. thuringiensis* and *B. bassiana* in management of yellow stem borer (*Scirpophaga incertulas* Walker) as compared to untreated control and suggest it to be used as alternative to conventional synthetic organic insecticides by incorporating it in an integrated pest management programme.

Similarly, higher yield return recorded in plots treated with *N. mitis* and *D. elliptica* extracts suggested that plant extracts have great potential in managing stem borer problem. Findings similar to the current study on potentiality of botanical extracts have been reportes by Mulungu *et al*. (2007) on the use of *N. mitis* against *Z. subfascialatus* in stored common beans (*Phaseolus vulgaris* L.) and by Muro (2010) on the use of *D. elliptica* extracts for the control of Melon fly (*B. cucurbitae*) in water melons (*Cittrullus lanatus* Thumb.).

Low yield losses in plots treated with biopesticides, botanical extracts and synthetic insecticide as compared to untreated control is in line with findings by Muralidharan and Pasalu (2005) who reported high rice yield losses of up to 95% in treatments without any control measures as compared to protected plots. Similarly the study by Way *et al.* (2006) reported rice yield losses of 60% due to stem borers' damage in unprotected field in Texas. A positive relationship between yield loss and stem borer damage incidences was recorded under this study which is consistent with the findings by Sherawat *et al*. (2007) who reported that rice yield losses was highly contributed by increased dead hearts and white heads. Further the study by Krishanaiah (1995) reported that for every per cent increase in white head incidence in rice crop leads to 1.3% grain yield loss.

Stem damages occurs as stem borer larvae make an internal feeding of the plant tissue which results into interference of nutrients and water uptake by plant from the soil (ISU, 2012). When this occurs during early stages of rice development results into death of the central shoot (dead heart) which prevents panicle initiation and when occurs after panicle initiation can result into development of empty spikelets (white head) which consequently lead to grain yield disadvantage. The findings that stem borers damage by tunnelling leads to reduction of grain yield is parallel with the study by Sigh *et al*. (2011) who reported that loss of maize grain due to stem tunnelling was greater than losses incurred due to leaf feeding. Furthermore, negative correlation of stem borers damage with yield and yield components is in line with studies by (Kega *et al*., 2016; Litsinger *et al*., 2011; Asghar *et al*., 2009) who describes grain yield to decreases with increasing stem borer infestation.

Findings from this study proved the efficacy of botanicals (*N. mitis and D. elliptica*) extracts in managing stem borer damages in rice. This protection can occur through repellent action of the extracts as insect ingest in attempting to feed on the crop leaves and for their larvae picking up the residues sprayed on leaves during spray or through foraging behaviour which ultimately suffer through feeding inhibition or high mortality, resulting in reduced crop damage (Ogah *et al*., 2011). Fungi based biopesticides have for the first time been proven effective against rice stem borer given the highly reduced stem borer damage incidence and high mortality of stem borer larvae. The fungi based biopesticides can affect the host as the insect cuticle comes in contact with the fungi during spray or during larvae movement. The fungi can then adhere to the host cuticle, germinates, form appressorium which penetrates to the insect body, colonize the haemolymph, extrudes and sporulates which finally lead to death of the host (Aw and Hue, 2017). High mortality rates of stem borer larvae were recorded in *B. bassiana* and *M. anisopliae* treated insects which were parallel with findings of Tefera (2004) and Terefe *et al*. (2012) who respectively reported high mortality of *C. partellus* and *S. calamistis* larvae treated with natural isolates of *B. bassiana* and *M. anisopliae* under controlled conditions.

Generally, study results reveals the potentiality of fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and botanical extracts (*D. elliptica* and *N. mitis*) as natural insecticides in the control of rice stem borers as alternative to synthetic insecticides. Rice grain yield increase in fungi based biopesticides and botanical extracts treated plots substantiates the potentiality of these natural insecticides. Stem borers' infestations results in economic damage to rice crop in many African countries especially for small scale farmers due to little knowledge on insecticide safety use and/or insecticides been very expensive. Therefore ideal stem borer control strategy that would suit the economy of rice cultivation at the smallholder sector level is the use of natural insecticides by including them in integrated rice stem borer management. Since the results from this study were obtained from the controlled environment, further studies under field conditions using the substances obtained from this study is important. This should be accompanied with studies on factors contributed to production of more tillers in rice infested by stem borers.

5.7 Conclusions

The study was conducted to assess the efficacy of fungi based biopesticides (*M. anisopliae* and *B. bassiana*) and two botanicals (*D. elliptica* and *N. mitis*) in controlling rice stem borers. It was found that, the use of biopesticides and botanicals are effective as chemical insecticides in reduction of stem borer incidences. The highest grain yield and high stem borer mortality rates were recorded in plots treated with fungi based biopesticides and botanicals extracts indicating their potentiality in controlling rice stem borers.

Acknoledgements

This study was supported by USAID Feed the Future IPM Innovation Lab, Virginia Tech, Cooperative Agreement No. AID-OAA-L-15-00001 through International Centre of Insect physiology and Ecology (ICIPE). Thanks are due to International Centre of Insect Physiology and Ecology for provision of stem borer larvae for laboratory and screen house trials. Also thanks should go to Real IPM Company for provision of fungi biopesticides used in this study.

References

Abbott, W. S. (1925). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology* 18: 265 - 267.

Akinbode, O. A and Ikotun, T. (2008). Evaluation of some bio-agents and botanicals in in-vitro control of *Colletotrichum destructivum*. *African Journal of Biotechnology* 7: 868 - 872.

Akinsola, E. A and Agyen-Sampong, M. (1984). The ecology, bionomics and control of rice stem-borers in West Africa. *Insect Science Application* 5: 69 – 77.

Asghar, M., Suhail, A., Afzal, M and Khan, M. A. (2009). Determination of economic threshold level of the stem borers (*Scripophaga* sp) and leaf hopper (*Cnaphalocrosis medilanis*) of rice (*Oryza sativa*) in Kallar truct of Punjab. *Pakistan Journal of Agriculture and Biology* 11: 717 - 720.

Aw, K. M. S and Hue, S. M. (2017). Mode of infection of *Metarhizium* spp. fungus and their potential as biological control agents. *Journal of Fungi* 3: 30.

Banwo, O. O. (2002). Management of major insect pests of rice in Tanzania. *Plant Protection Science* 38(3): 108 – 113.

Bosque-P´erez, N. Aand Mareck, J. H. (1991). Effect of the stem borer *Eldana saccharina* Lepidoptera: Pyralidae) on the yield of maize. *Bulletin of Entomology Research* 81: 243 – 247.

Chatterjee, S and Mondal, P. (2014). Management of rice yellow stem borer, *Scirpophaga incertulas* Walker using some biorational insecticides. *Journal of Biopesticide* 7: 143 – 147.

Gomez, K. A and Gomez, A. A. (1984). *Statistical procedures for agricultural research*. 2nd Edition. John Wiley and Sons., New York. 680pp.

Hailu, T., Selvaraj, T., Mengistu, L and Negery, M. (2012). Evaluation of some native entomopathogenic fungi against pink stem borer (*Sesamia calamistis* Hampson) (Lepidoptera: Noctuidae) in sugarcane. *Pest Management Journal of Ethiopia* 7: 1 - 9.

Harris, K. M. (1990). Bio ecology and *Chilo* species. *Insect Science Application* 11: 467 – 77.

Hasan, M., Chowdhury, M. S. P., Alam, S., Hossain, B and Alam, M. S. (2005) Antifungal effects of plant extracts on seed-borne fungi of wheat seed regarding seed germination, seedling healthy and vigor index. *Journal of Biological Science* 8: 1284 - 1289.

Islam, M. S., Das, S., Islam, K. S., Rahman, A., Huda, M. N and Dash, P. K. (2013). Evaluation of different insecticides and botanical extracts against yellow stem borer, *Scirpophaga incertulas* in rice field. *International Journal of Bioscience* 3(10): 117 - 125.

ISU (Iowa State University) (2012). *Field crop insects*. Iowa Soybean Association. 4 - 5pp.

January, B., Rwegasira, G. M and Tefera, T. (2018). Lepidopteran stem borer species abundance and associated damages on irrigated Kilombero low land rice ecosystem in Tanzania. *Journal of Entomology* 15: 28 - 35.

Kega, V. M., Kasina, M., Olubayo, F and Nderitu, J. H. (2017). A Study of the African white rice stem borer (*Maliarpha separatella* Rag.) population density fluctuations at Mwea irrigation scheme in Central Kenya. *Universal Journal of Agricultural Research* 5(1): 52 - 56.

Kega, V. M., Okebayo, F., Kasina, M and Nderitu, J. H. (2016). Assessment of yield loss caused by the African white rice stem borer (*Maliarpha separatella* Rag (Lepidoptera: Pyralidae) at Mwea irrigation scheme, Kirinyaga County, Kenya. *Journal of Entomology* 13: 19 - 25.

Kfir, R., Overholt, W. A., Khan, Z. R and Polaszek, A. (2002). Biology and management of economically important lepidopteran cerial stem borers in Africa**.** *Annual Revew of Entomology* 47:701 –7 11.

Khan, A. B., Muhammad, A., Arif, A. M and Khan, M. (2013). Toxicity of botanicals and selective insecticides to Asian citrus psylla, *Diaphorina citri* K. (Homoptera: Psyllidae) in laboratory conditions. *Jokull Journal* 63(8): 52.

Krishanaiah, K. (1995). Technology for rice production. DRR. ICAR, Rajendranagar, Hyderabad. Ecology of common insect pests of rice. *Annual Review of Entomology* 13: 257 - 294.

Lasisi, A. A and Adesomoju, A. (2015). Neoraudiol, a new isoflavonoid and other antimicrobial constituents from the tuberous root of *Neorautanenia mitis* (A. Rich) Verdcourt. *Journal of Saudi Chemical Society* 19 (4): 404-409.

Leonard, A and Rwegasira G. M. (2015). Abundance and spatial dispersion of rice stem borer species in Kahama, Tanzania. *Journal of Insect Science* 15(1): 132.

Litsinger, J. A., Bandong, J. P and Canapi, B. L. (2011). Effect of multiple infestations from insect pests and other stresses to irrigated rice in Philippines. *International Journal of Pest Management* 57: 117 - 131.

Mailafiya, D. M., Le Ru, B. P., Kairu, E. W., Dupas, S., Calatayud, P. A. (2011). Parasitism of lepidopterous stem borers in cultivated and natural habitats. *Journal of Insect Science* 11: 15.

Majlish, A. K., Uddin, M. M., Jahan, M and Rahman, M. M. (2015). Comparative efficacy of different botanicals and chemical insecticides for controlling rice stem borer. *Journal of Bangladesh Agricultural University* 13(2): 183 – 189.

Manisegaran, S, Lakshmi, S. M and Srimohanapriya, V. (2011). Field evaluation of *Metarhizium anisopliae* (Metschnikoff) Sorokin against *Holotrichia serrata* (Blanch) in sugarcane. *Journal of Biopesticides* 4(2): 190 - 193.

Mghase, J., Shiwachi, H., Nakasone, K and Takahashi, H. (2010). Agronomic and socio-economic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research* 5(2): 150 - 158.

Mgoo, V. H, Makundi. R. H., Pallangyo, B., Schulthess, F., Jiang, N and Omwega, C. (2006). Yield loss due to the stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) at different nitrogen application rates to maize. *Annals Society Entomology of France* 42: 3 - 4.

Mishra, S., Kumar, P and Malik, A. (2015). Effect of temperature and humidity on pathogenicity of native *Beauveria bassiana* isolate against Musca domestica L. *Journal of Parasitology and Diseases* 39(4): 697 – 704.

Mulungu, L. S., Luwondo, E. N., Reuben, S. O. W and Misangu, R. N. (2007). Effectiveness of local botanicals as protectants of stored beans (*Phaceolus vulgaris* L) against bean bruchid (*Zabrotes subfaciatus* Boh). *Journal of Entomology* 4: 210 – 217.

Mulungu, L. S., Ndilahomba, B., Nyange, C. J., Mwatawala, M., Mwalilino, J. K., Joseph, C. C and Mgina, C. A. (2011). Efficiency of *Chrrysanthemum cinerariaefolium*, *Neurautanenia mitis* and *Gnidiakra ussiana* against larger grain borer (*Prostephanus truncutus* Horn) and maize weevil (*Sitophilus zeamays* L.) grain seeds. *Journal of Entomology* 8: 81 – 87.

Muralidharan, K and Pasalu, I. C. (2005). *Assessments of crop losses in rice ecosystems due to stem borer damage (*Lepidoptera: Pyralidae*).* Indian Council of Agricultural Research. New Delhi. 18pp.

Muro, L. C. (2010). Effcacyof locally formulated baits in managing the melon fly *Bactrocera cucurbitae* (Coquilet) (Diptrrs: Tefritidae). A Dissertation Submitted in partial fulfilment of the requirements for the degree of Master of Science in Crop Science, Sokoine university of Agriculture, Morogoro. 56pp.

Nduagu, C. E., Ekefan, J., Nwankiti, A. O. (2005). Effect of some crude plant extracts on growth of *Colletotrichum capsici* (Synd) Butler and Bisby, Causal agent of pepper anthracnose. *Journal of Applied Bioscience* 6: 184 - 190.

Nwilene, F. E., Sanyang, S., Traore, A. K., Togola, A., Goergen, G., Agunbiade, T.A., Tamo, M., Akintayo, I., Cissé, B and Ogah, E. (2009). *Rice Stem Borers: Biology, ecology and control.* Field guide and technical manual. Africa Rice Center, Cotonou, Benin. 28pp.

Ogah, E. O. (2013). Field evaluation of plant extracts in the management of *Megalurothrips sjostedti* and *Maruca vitrata* of cowpea in South Eastern Nigeria. *World Essays Journa*l 1: 11 - 17.

Ogah, E. O., Omoloye, A. A., Nwilene, F. E., Nwogbaga, A. C. (2011). Effect of neem seed kernel extracts in the management of rice stem borers in the field in Nigeria. *Nigerian Journal of Biotechnology* 23: 13 - 21.

Oparaeke, A. M., Dike, M. C., Amatobi, C. I. (2005). Evaluation of botanical mixtures for insect pest's management on cowpea plants. *Journal of Agriculture and Rural Development in Tropics and Subtropics* 106 (1): 41 – 48.

Prakash, A., Rao, J and Nandagopal, V. (2008). Future of botanical pesticides in rice, wheat, pulses and vegetables pest management. *Journal of Biopesticides* 1: 154 - 169.

Prasad, S. S, Gupta, A. K. (2012). Compatibility of new insecticides and fungicides against stem borer and leaf blast on semi-deep water rice. *Crop Research* 43 (3): 197 - 200.

Rahman, T., Khalequzzaman, M and Rahman, M. A. (2004). Assessment of infestation and yield loss by stem borers on different variety of Rice. *Journal of Asia-Pasific Entomology* 7(1): 89 – 95.

Sarwar, M. (2012). Effects of potassium fertilization on population build-up of rice stem borers (lepidopteron pests) and rice (*Oryza sativa* L.) yield. *Journal of Cereals and Oil seed*s 3(1): 6 - 9.

Seshu Reddy, K. V. (1988). Assessment of on-farm yield losses in sorghum due to insect pests. *Insect Science Application* 9: 679 – 85.

Shahid, A. A, Nasir, I. A., Zafar, A. U., Sumrin, A., Chaudhry, B and Riazuddin, S. (2009). The use of Camb biopesticides to control pests of rice (*Oryza sativa* L.*). Asian Journal of Plant Science* 2: 1079 - 1082.

Shahid, A. A., Rao, A. Q., Bakhsh, A., Husnain, T. (2016). Entomopathogenic fungi as biological controllers: New insights into their virulence and pathogenicity. *Achieves of Biological Science Belgrade* 64 (1): 21 - 42.

Sherawat, S. M., Inayat, M., Ahmad, T and Maqsood, M. K. (2007). Determination of economic threshold level (ETL) for the chemical control of rice borers. *Journal of Agricultural Research* 45: 55 - 59.

Singh, B. U., Sharma, H. C and Rao, K. V. (2011). Mechanisms and genetic diversity for host plant resistance to spotted stem borer, *Chilo partellus* Swinhoe in sorghum (*Sorghum bicolor* L.) *Journal of Applied Entomology* 135: 333 - 392.

Suresh, K., Bhaskaran, R. K. M., Santhilkumaran, S., Rajaval, M and Shanti, K. (2009). Effect of organic sources of nutrient on management of sucking pest of *Cassia angustifolia*. *Journal of Plant Protection Science* 17: 32 - 36.

Sylvain, N. M. (2015). Effect of lepidopterous stemborers, *Busseola fusca* (Fuller) and *Chilo Partellus* (Swinhoe) on Maize (*Zea mays* L) Yield: A Review. *International Journal of Innovation Research and Development* 4: 10.

Tefera, T and Pringle, K. L. (2007). Biological control of the spotted stem borer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) with the entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae*. *Ethiopian Journal of Science* 30: 65 - 70.

Tefera, T. (2004). Germination, radial growth, and sporulation of *Beauveria bassiana* and *Metarhizium anisopliae* isolates and their virulence to *Chilo partellus* (Lepidoptera: Pyralidae) at different temperatures. *Biocontrol Science and Technology* 13: 699 – 704.

Tefera, T., Mugo, S., Tende, R and Likhayo, P. (2011). Methods of screening maize for resistance to stem borers and post-harvest insect pests. CIMMYT. Nairobi, Kenya. 39pp.

Terefe, T. H, Selvaraj, T., Mengistu, L and Negery, M. (2012). Evaluation of some native entomopathogenic fungi against pink stem borer (*Sesamia calamistis* Hampson) (Lepidoptera: Noctuidae) in sugarcane. *Journal of Agricultural Technology* 8(2): 515 - 536.

Teshome, A and Tefera, T. (2009). Susceptibility of *Sitophilus zeamais* (Mostch.) (Coleoptera: Curculionidae) to *Beauveria bassiana* and *Metarhizium anisopliae. Ethiopian Journal of Science* 32(1): 21 – 28.

Ukwungwu, M. N and Odebiyi, J. A. (2008). Yield losses in resistant and susceptible varieties of rice in Nigeria due to *Chilo zacconius* and other stem borers. *International Journal of Pest Management* 30: 3.

Van Den Berg, I, Van Den Berg, J. B and Pringle, K. L. (1990). Damage caused by *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) to various cultivars of grain sorghum, *Sorghum bicolor* (L.) Moench. *South African Journal of Plant and Soil,* 7: 192 - 196.

Visetson, S and Milne, M. (2001). Effects of root extract from Derris (*Derris elliptica* Benth) on mortality and detoxification enzyme levels in the Diamond back moth larvae (*Plutella xylostella* Linn.). *Kasetsart Journal of Natural Science* 35: 157 - 163.

WARDA. (2006). Medium term plan for 2007 - 2009. *Charting the future for rice in Africa*. Africa Rice Centre, Cotonou. 13 - 14pp.

Way, M. O., Jones, R and Reagan, T. E. (2006). Resitance to stem borers Lepidoptera: Crambidae) among Texas rice cultivars. *Journal of Economic Entomology* 99: 1867 – 1876.

Zubairi, S. I., Sarmidi, M. R and Aziz, R. A. (2014). A Study of Rotenone from Derris roots of varies location, plant parts and types of solvent used. *Advanced Environtal Biology* 8(2), 445-449.

CHAPTER SIX

6.0 EFFECTS OF PLANT SPACING AND NITROGEN FERTILIZER RATES ON STEM BORER DAMAGE AND RICE YIELD IN KILOMBERO, TANZANIA

Published in *International Journal of Pest management*; 1: 1-7.

doi:10.1080/09670874.2020.1737342

Abstract

Nitrogen fertilization and plant spacing hold potential for the integrated management of rice insect pests. Field experiments were conducted in Kilombero, Tanzania to evaluate the effects of plant spacing and nitrogenous fertilizer on incidences and density of spotted and African pink stem borers. A 3 × 4 × 4 factorial experiment was used in a randomized complete block design with three replications. Treatments included application of urea fertilizer at four levels (0, 40, 80, and 160 kg N ha^{-1}) and spacing at four levels (10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, and 25 cm × 25 cm). Nitrogen significantly increased dead hearts by 4.8%, white heads by 2.8% and stem borer larvae density from 0 to 5.6 larvae/m^2. Decreasing the planting density significantly increased dead hearts by 4.7%, white heads by 2.7% and stem borer larvae density from 0 to 5.4 larvae/m^2. The interaction of nitrogen fertilizer rates and plant spacing did not affect stem borer incidences nor larvae density, but did influence the rice yield.

Key words: *Chilo partellus*, *Sesamia calamistis*, incidences, stem borer larvae density, nitrogen fertilizer, spacing, rice yield

6.1 Introduction

Rice (*Oryza sativa* L.) is attacked by numerous insect pests, both in the field and in storage. The most important insect pests of rice in the field reported in Africa include lepidopterous stem borers, which belong to the Noctuidae and Pyralidae families (Sarwar, 2011; January *et al*., 2018a), and dipterous stem borers, which belong to the Diopsidae family (Banwo *et al*., 2002). Stem borers infest rice crops from the nursery through to harvesting by attacking the tillers and panicles, particularly at panicle initiation stage (Ranasinghe, 1992; Sarwar, 2011). The caterpillars (destructive stage) bore into rice stems and hollow out the stem completely, resulting in damage to the plant. The damage intensity depends on the growth stage of the plant at which it is attacked by stem borers (Indike, 2002).

When stem borers infest a plant during the vegetative stage, it causes a symptom of damage called ‘dead heart’ (Pathak and Khan, 1994). This occurs as a result of the larvae feeding on the terminal shoot, and causes the stem to turn brown, wilt, and die. But if the infestation occurs during the flowering stage, it results in a symptom of damage known as ‘white head’. This causes the panicles to bear empty spikelet (Pathack and Khan, 1994). Stem borer damage incidences of approximately 30-50% of plant tillers have been reported in many rice-producing countries in Africa (Ogah, 2013). It is estimated that for every 1% incidence of white heads, the expected yield loss will be 1-3% (Touhidur *et al*., 2004). In Tanzania, dead heart incidences ranged from 0.56 - 7.57% and white head incidences ranged from 0.34 - 2.89%; substantial yield losses of 3 - 9% due to stem borers have been reported (Leonard, 2015).

Chemical insecticides have been suggested for use in controlling stem borers (Prasad and Gupta, 2012; URT, 2014), but most are reportedly ineffective owing to the cryptic nature of the pest attack (January *et al.*, 2008b). Chemical insecticides, however, need to be avoided owing to their harmful side effects for humans, animals, and birds, as well as their negative effects on the environment and beneficial organisms (Singh *et al.*, 2015). Attempts to avoid the excessive use of insecticides have always prompted interest in cultural, physical, and biological control options. Although physical and biological options are somewhat tricky to deploy under farm conditions, cultural options are often practical and manageable by farmers. The integration of adjusted plant populations through the control of plant spacing and the amount of fertilizer applied as either basal or top dressing on crops has been reported to reduce infestation and subsequent damage caused by stem borers in maize (Ali, 2006; Arshad *et al.*, 2013). This study aims to determine whether similar outcome can be achieved with rice. Moreover, the study aims to strike an ecological balance between stem borer control and yield increases to ensure sustainable food production with minimal environmental effect, while sustaining resources for future generations (Nwilene *et al.*, 2013).

Manipulation of nitrogenous fertilizer rates and plant spacing may provide good results for the integrated management of rice insect pests (Ogah *et al.*, 2005). Sarwar (2012) reported that high rice stem borer infestation rates were linked to high fertilizer rates. Dense plant spacing changed crop growth, development, and microclimate, which had an effect on pests and their natural enemies (Litsinger, 1994). Wide plant spacing treatments encourage the growth of other plants, including weeds (i.e. invasive plant species). These increase plant biodiversity, and therefore also increase animal biodiversity, some of which act as natural enemies to major pests. Litsinger (1994) reported that wide plant spacing treatments encourage weeds and have an indirect effect on insect abundance. Nevertheless, the presence of weeds in rice fields can be beneficial or non-beneficial. In some cases, the vegetation diversity inherent to the presence of weeds supports a higher number of prey arthropods, and that in turn supports natural enemies of the pest species (Showler, 2004). However, in some cases, such increases in biodiversity might exert a competitive effect on the crop, weakening crop vigour and promoting susceptibility to pests and diseases.

The potential of cultural control practices in the management of rice stem borers have not been exploited by many African farmers (Rami *et al*., 2002). Available information to support the effectiveness of cultural practices is limited. Limited access to the data from existing studies, despite their novelty, often leads to hesitation in the adoption of such practices. One such example is the limited information available regarding the influence of nitrogenous fertilizers and plant spacing in promoting or deterring damage by rice stem borers (Baidoo, 2004; Ogah, 2005; Ali, 2006; Wale *et al*., 2006). The interaction effects of stem borers and nitrogen fertilizer on rice have received little interest in the literature. Increased understanding of this would improve the efficiency of fertilizer use by resource-poor farmers, while controlling stem borer infestation in order to increase the productivity of rice. In sub-humid areas with heavy rainfall, such as Tanzania, substantial losses of nitrogen are encountered through leaching. In these regions, understanding the interaction effects of fertilizer and plant spacing would assist with increasing the productivity of rice through fertilizer usage and stem borers’ management. This study, therefore, reports on the combined effects of fertilizers and plant spacing on stem borer abundance and damage.

6.2 Materials and Methods

6.2.1 Description of the study site

A study was conducted in two consecutive years on a low land rice crop grown under irrigation in the Kilombero District, Tanzania. Three wards, Sanje (7° 45′ 33.1981″ S, 36° 55′ 15.0247″ E; 307.788 m a.s.l.), Mkula (7° 46′ 4.2672″ S, 36° 56′ 43.4076″ E; 261.27 m a.s.l), and Signali (8° 0′ 1.4234″ S, 36° 50′ 13.5179″ E; 264 m a.s.l) were included in the study. The sites are major producers of rice and stem borers are major pest. Mkula and Sanje are located close to Udizungwa National Park Mountain where there is reservation of natural vegetation and water throughout the year. The only crop cultivated under this two locations is rice with exceptional of Mkula where they also cultivate sugar cane. Signali is located away from Udizungwa National Park where there is no reservation of natural vegetation and water for irrigation is scarce. Partly of Signali farmers are cultivating rice through irrigation and the rest are through rain fed. Other food crops such as maize are also cultivated by Signali farmers. The growing seasons covered the period from July to November in 2017 and from February to June in 2018. The three wards experience bimodal rainfall pattern characterized by two rainfall peaks in a year, with a definite dry season separating the short and long rains. The short rain season is from July to December while the long rain season starts from March and ends in May (Msanya *et al*., 2003). The meteorological data for 2017 and 2018 are shown in Figure 6.1. The experimental sites were flat, with a mean rainfall of 124.88 mm, a minimum temperature of 19 °C, a maximum temperature of 30 °C, and a relative humidity of 50% during the 2017 season, and a mean rainfall of 49.83 mm, a minimum temperature of 20 °C, a maximum temperature of 31 °C, and a relative humidity of 60% during the 2018 season. Meteorological data only considered the period during which experiments were being conducted and were all in the range that favours healthier growth of rice crop (Goswami *et al* ., 2006).

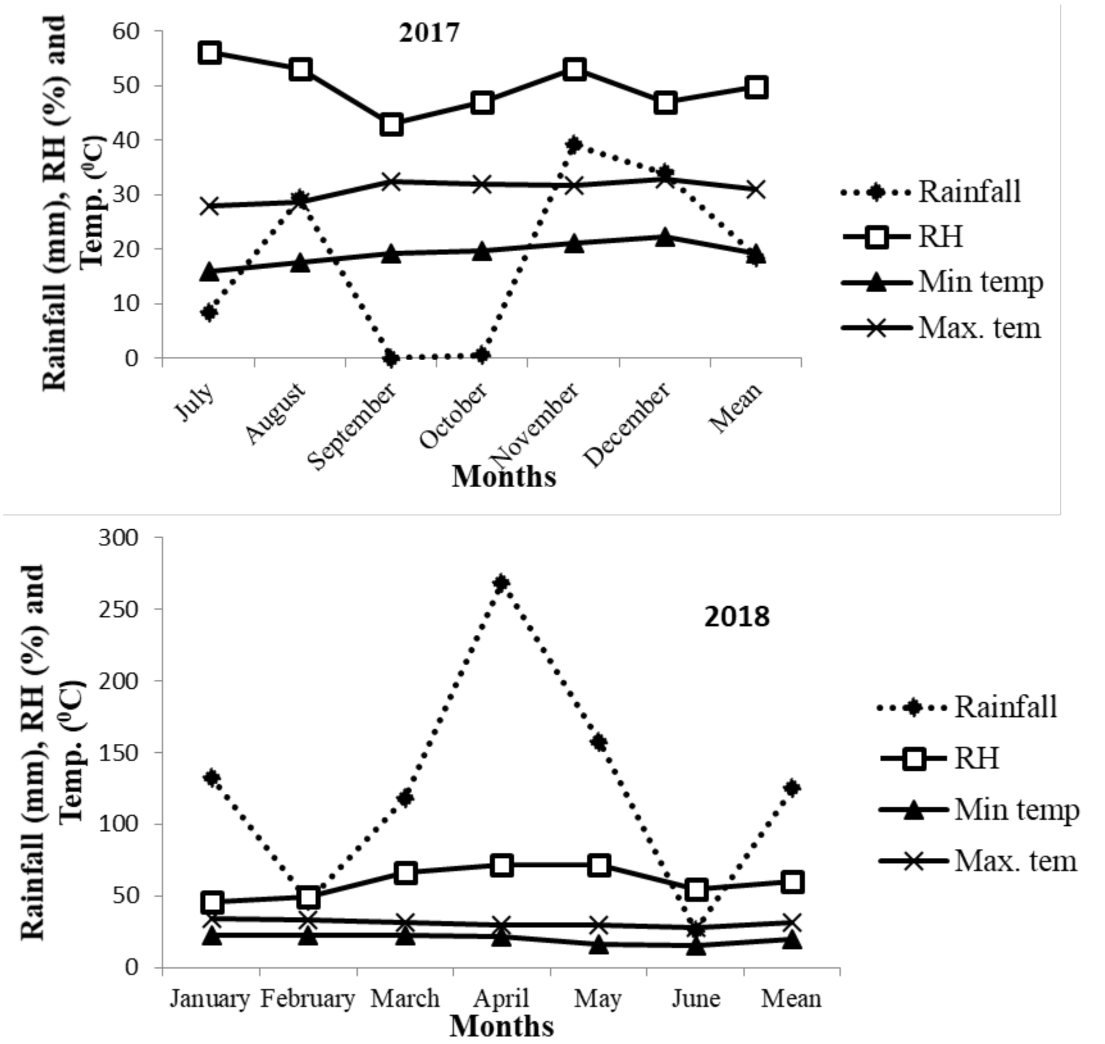


Figure 6.1: Weather parameters of the study site during experimental period

6.2.2 Soil sampling

Soil samples were collected from each experimental field at least three months prior to planting and sent for analysis of chemical and physical properties at the Department of Soil Science Commercial Testing Laboratory, Sokoine University of Agriculture, Morogoro, Tanzania. Some physicochemical properties of the soils are as shown in Table 6.1. Based on the obtained data, the soil was classified as sandy clay loam and clay loam (Amuri *et al*., 2017). The total soil nitrogen prior to the experiments was 0.16%, and was 0.18% after the experiments, which is considered to be low according to Dobermann and Fairhust (2000). The total nitrogen were similar prior experiment and after experiment due to leaching and up take by plant. The soil pH ranged between 5.19 - 5.58, and Potassium between 0.11 - 0.28 cmol $_{(+)}$ kg^{-1} which falls in the low to medium ranges, whereas Phosphorous concentration in soil ranged between 4.8 - 8.85 (mg/kg) which is below critical level of 15 mg /kg according to (Landon, 1991).

Table 6.1: Chemical and physical properties of the soil samples in the trial sites

Year	Site (wards)	pH	Total N (%)	Available P (mg/kg)	Exchangeable K (cmol (+)/kg)	Organic Carbon (%)	Clay (%)	Silt (%)	Sand (%)	Soil type
	Signali	5.5	0.12	8.85	0.21	2	24.7	13.1	62.1	Sand clay loam
2017	Msufini	5.19	0.16	4.8	0.16	1.95	33.4	10.3	56.3	Clay loam
	Sanje	5.64	0.12	1.25	0.13	2.1	29.4	14.3	48.4	Clay loam
	Signali	5.61	0.14	7.76	0.11	1.8	36.4	37.7	26.9	Sand clay loam
2018	Msufini	5.54	0.18	3.04	0.17	2.02	30.7	12.2	56.1	Clay loam
	Sanje	5.68	0.14	1.63	0.28	2.32	27.3	24.3	48.4	Clay loam

6.2.3 Experimental design and planting

A 3 × 4 × 4 factorial experiment was used in a randomized complete block design (RCBD) with three replications. Treatments included three locations (Sanje, Mkula, and Signali wards, see GPS references in section 6.2.1), urea fertiliser applied at four levels (0, 40, 80, and 160 Kg N ha^{-1}) and plant spacing at four levels (10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, and 25 cm × 25 cm). Using these plant spacing treatments, the estimated planting densities were 1000 000, 250 000, 444 444, and 160 000 plants ha^{-1}, respectively. The nitrogen rates and spacing used were respectively selected based on recommendations suggested by Mbaga *et al*. (2017) for nitrogen rates of 50 – 200 Kg N ha^{-1} and Reuben *et al*. (2016) for spacing of 15 cm x 15 cm, 20 cm x 20 cm, 25 cm x 25 cm, 30 cm x 30 cm and 35 cm x 35 cm for optimum yielding of rice in most Tanzanian soils. The tested N levels were nested within plant spacing such that levels N levels were included as subplots within main plots that differed in plant spacing. The rice cultivar 'TXD 306', which is commonly grown by many farmers and is known to be susceptible to stem borers, was used. The total experimental area at each site (ward) was 1404 m^2 (39 m × 36 m) with treatment plots measuring 20 m^2 (5 m × 4 m). Each treatment plot was partitioned using 0.5 m × 0.5 m bunds. The separating distance between blocks (468m^2 block size) and experimental plots was 1 m and 0.5 m, respectively. Transplanting was undertaken at 14 days after nursery establishment, with one seedling planted per hole. Urea fertilizer was added in two doses, 50% at 3 days after transplanting (DAT) and 50% at panicle initiation in respective treatment plots. A blanket application of 40 kg P ha^{-1} of Triple Super phosphate and 40 kg K ha^{-1} muriate of potash was added to all the plots as basal treatments once at 3 DAT. Other agronomic practices such as weeding and irrigation were conducted regularly (Mghase *et al*., 2010). No pesticide was used in the experimental fields.

6.2.4 Data collection and analysis

Collected data included incidences of stem borer (dead heart and white head damage), stem borer larvae density, agronomic parameters including stem diameter, Chlorophyll content, succulent content, and grain yield. The damage, larvae density and agronomic parameters were assessed from plants in a 1 m^2 sampling area in each treatment plot. Damage data were collected twice, at 42 DAT for dead hearts and 72 DAT for white heads whereas that of larvae density were collected once at 72DAT. The incidences of stem borers were calculated using the formula described by Suresh *et al*. (2009) as follows;

$$\text{Stem borer incidence \%} = \frac{\text{Number of dead hearts or white heads}}{\text{Total number of productive tillers}} \text{X100} \quad \text{……. (xi)}$$

Stem diameter and chlorophyll content were measured once by randomly selecting one tiller from every plant hill in 1 m^2 sampling area at 72 DAT. The total number of sampled plant hills per sampling area were 100 plants from 10 cm x 10 cm, 45 plants from 15 cm x 15 cm, 25 plants from 20 cm x 20 cm and 16 plants from 25 cm x 25 cm plant spacing. Stem borer larvae density were obtained by counting the number of larvae after dissection and removal of larvae from the rice stems in a sampled 1m^2 area. Identification of stem borer species was according to the method of Pathack and Khan (1994). The diameter of stem segments was measured at the fifth, sixth, and seventh phytomer positions of selected tillers' stems using digital callipers, and the average of the three measurements recorded (Kato *et al*., 2007). The chlorophyll content was measured using a soil plant analysis development chlorophyll meter (*SPAD*-502). Measurements were taken once on the longest leaf (flag leaf) of a selected tiller from plant hill in a sampling area, and the average SPAD readings recorded (Yuan *et al*., 2016). Water content was determined at harvesting by measuring samples of five plants from each 1 m^2 sampling area from each plot after threshing (removal of grains) while fresh and oven drying for 24 hours at a constant temperature of 75 °C. Grain yield (t ha^{-1}), standardised to 14% moisture content, and was computed from shelled and winnowed grains in a 12 m^2 quadrat area that had been marked earlier in every plot. The 1 m^2 sampled area for agronomic parameters were also included within the 12 m^2, the sampling area for grain yield computation. The stem borer incidence, larvae density, agronomic parameters and yield data were tested for normality using R statistical software (2016) and found to conform to normal distributions and therefore there was no need for transformation.

Data were subjected to analysis of variance (ANOVA) using R statistical software (2016). Analysis was performed for all collected data, separately for each year. Significant differences among means were separated using the Student Newman Keuls test (SNK) test at the $p \leq 0.05$ level of significance. The analysis model was according to Gomez and Gomez (1984) for factorial experiments, i.e. $Y_{ijkl} = \mu+T_i+\beta_j+yk+(T\beta)_{ij}+(Ty)_{ik}+(\beta y)_{jk}+(T\beta y)_{ijk}+eijkl$; Where Y_{ijk} = response; μ = mean; (T_i, β_j and yk) are the effects of i^{th} site, j^{th} nitrogen level and k^{th} plant spacing; $(T\beta)_{ij}$,$(Ty)_{ik}$ and $(\beta y)_{jk}$ are the two factor interactions for site vs. nitrogen level, site vs. plant spacing and nitrogen level vs. plant spacing; $(T\beta y)_{ijk}$ are the interaction effects for the i^{th} site, j^{th} nitrogen level and k^{th} plant spacing; eijkl is the random error of the k^{th} observation from i^{th} site, j^{th} nitrogen and k^{th} plant spacing.

6.3 Results

6.3.1 Effects of locations on incidences and density of stem borers

Dead heart incidences ranged from 3.1% to 4.5% while the white head incidence ranged from 1.39% to 2.7%. There were significant differences in both dead heart (F = 11.93; df =2, 94; $P < 0.001$) and white head incidences (F = 13.41; df =2, 94; $P < 0.001$) in 2017, and dead heart (F = 11.92; df = 2, 94; $P < 0.001$) and white head incidences (F = 12.9; df

=2, 94; *P* < 0.001) in 2018 (Table 6.2). Among the three wards studied, Signali had more damage incidences than both Mkula and Sanje.

The density of stem borers were significantly different for *C. partellus* (F = 130.46; df =2, 94; *P* < 0.001), and *S. calamistis* (F = 41.82; df =2, 94; *P* < 0.001) in 2017 and C. partellus (F = 100.86; df =2, 94; *P* < 0.001) and *S. calamistis* (F = 48.15; df =2, 94; *P* < 0.001) in 2018 cropping season (Table 6.2). Among the three wards studied, Signali and Mkula had higher density of stem borers than Sanje.

Table 6.2: Incidences and density of steborers in different wards

Ward site	2017				2018			
	Stem borer incidence (%)		Stem borer larvae density/m²		Stem borer incidence (%)		Stem borer larvae density/m²	
	DH	WH	*C. partellus*	*S. calamistis*	DH	WH	*C. partellus*	*S. calamistis*
Sanje	3.82 ± 0.21a	2.07 ± 0.19a	2.333± 0.28a	0.5± 0.10a	3.12 ± 0.21a	1.39 ± 0.19a	1.479± 0.26a	0.125± 0.07a
Mkula	4.3 ± 0.21b	2.53 ± 0.19b	3.625± 0.23b	1.083± 0.07b	3.6 ± 0.09b	1.83 ± 0.07b	2.771± 0.19b	0.4792± 0.06b
Signali	4.52 ± 0.14b	2.72 ± 0.12b	5.542± 0.13c	1.625± 0.05c	3.82 ± 0.13b	2.03 ± 0.11b	4.667± 0.08c	0.9167± 0.04c
C.V	3.9	4.4	5.2	6.6	4.7	5.5	5.6	6
p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

DH = dead heart; WH = white head; SE = standard error. Means followed by the same letters within column are not significantly different (p > 0.05) (SNK).

6.3.2 Effects of nitrogen and plant spacing on stem borer incidences

Significant differences were observed for the 2017 cropping season in stem borer dead heart incidences between nitrogen levels (F =21.02; df = 3, 94; P < 0.001) and plant spacing (F = 62.14; df =3, 94; P < 0.001), but not for their interactions (F =1.62; df = 9; P = 0.12). Likewise, nitrogen levels (F = 12.56; df = 3, 94; P < 0.001) and plant spacing (F = 31.72; df =3; P < 0.001) had a significant influence on white head incidence, with the exception of the interactions of these two factors (F =1.09; df = 9, 94; P = 0.378) (Fig. 6.2 (A, B); Appendix 3). Similar trends were also recorded during 2018 cropping season for the influence of nitrogen and plant spacing on stem borer damage (P < 0.001), again apart from their interactions (P > 0.05) (Fig. 6. 3 (A, B); Appendix 3).

Rice stem borer damage increased with increasing levels of nitrogen fertilization, as well as with wider spacing (lower plant populations). A fertilizer rate of 160 Kg N ha^{-1} was recorded to have the highest incidences of stem borer damage in both experimental periods, with the lowest recorded in control plots. Similarly, the incidence of damage increased as the plant population decreased from 1000 000 plants to 160 000 plants ha^{-1} (i.e. as plant spacing increased) in both the 2017 and 2018 cropping seasons (Fig. 6.2 (A, B).

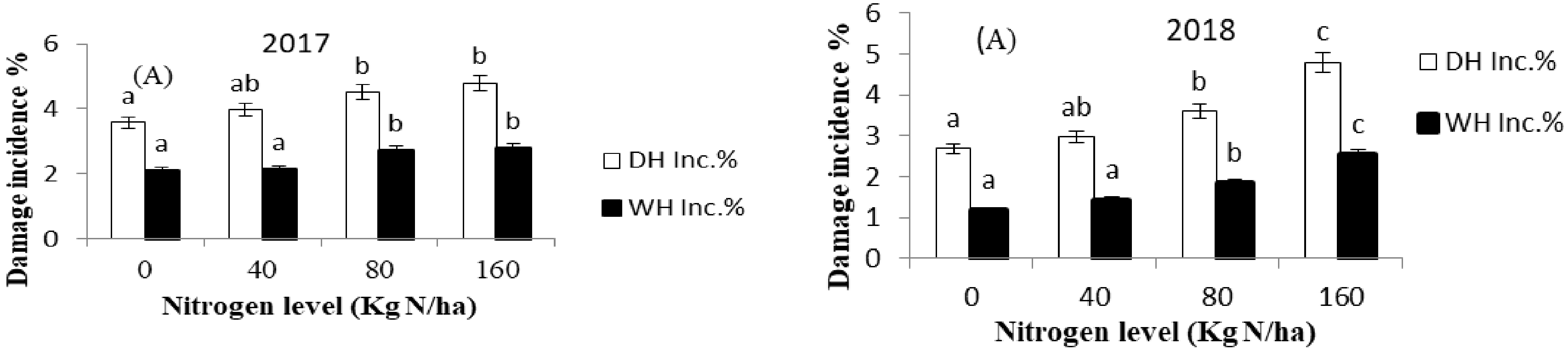


Figure 6.2: The effects of nitrogen on stem borer incidences

Bars followed by the same letters are not significantly different (*P* > 0.05) based on SNK test.

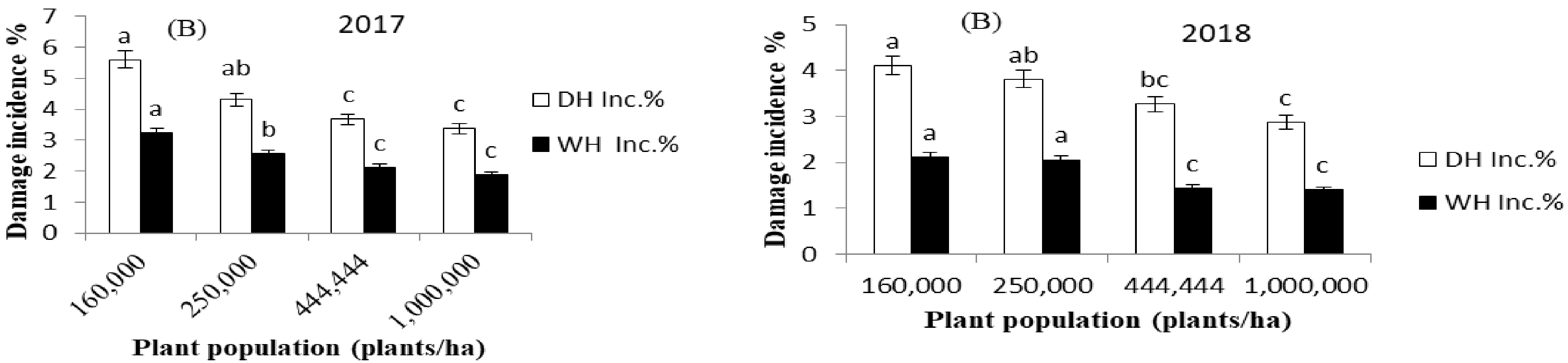


Figure 6.3: The effects of plant spacing on stem borer incidences

Bars followed by the same letters are not significantly different (*P* > 0.05) based on SNK test.

6.3.3 Effects of nitrogen and plant spacing on stem borer density

Significant effects were observed for the 2017 cropping season on stem borer larval density for nitrogen levels and plant spacing ($P < 0.001$), but their interactions were non significant (Fig. 6.3 (A, C). Similarly, significant difference were observed for the 2018 cropping season for the influence of nitrogen and plant spacing on stem borer larval density ($P < 0.001$), again apart from their interactions ($P > 0.05$) (Fig. 6.3 (B, D).

Stem borer density increased with increasing levels of nitrogen fertilization, as well as with wider spacing (lower plant populations). A fertilizer rate of 160 kg N ha^{-1} was recorded to have the highest stem borer larvae density in both the 2017 and 2018 cropping seasons. Moreover, the stem borer larvae density increased as the plant population decreased from 1000 000 plants to 160 000 plants ha^{-1} (i.e. as plant spacing increased) in both the 2017 and 2018 cropping seasons (Fig. 6.3B and D).

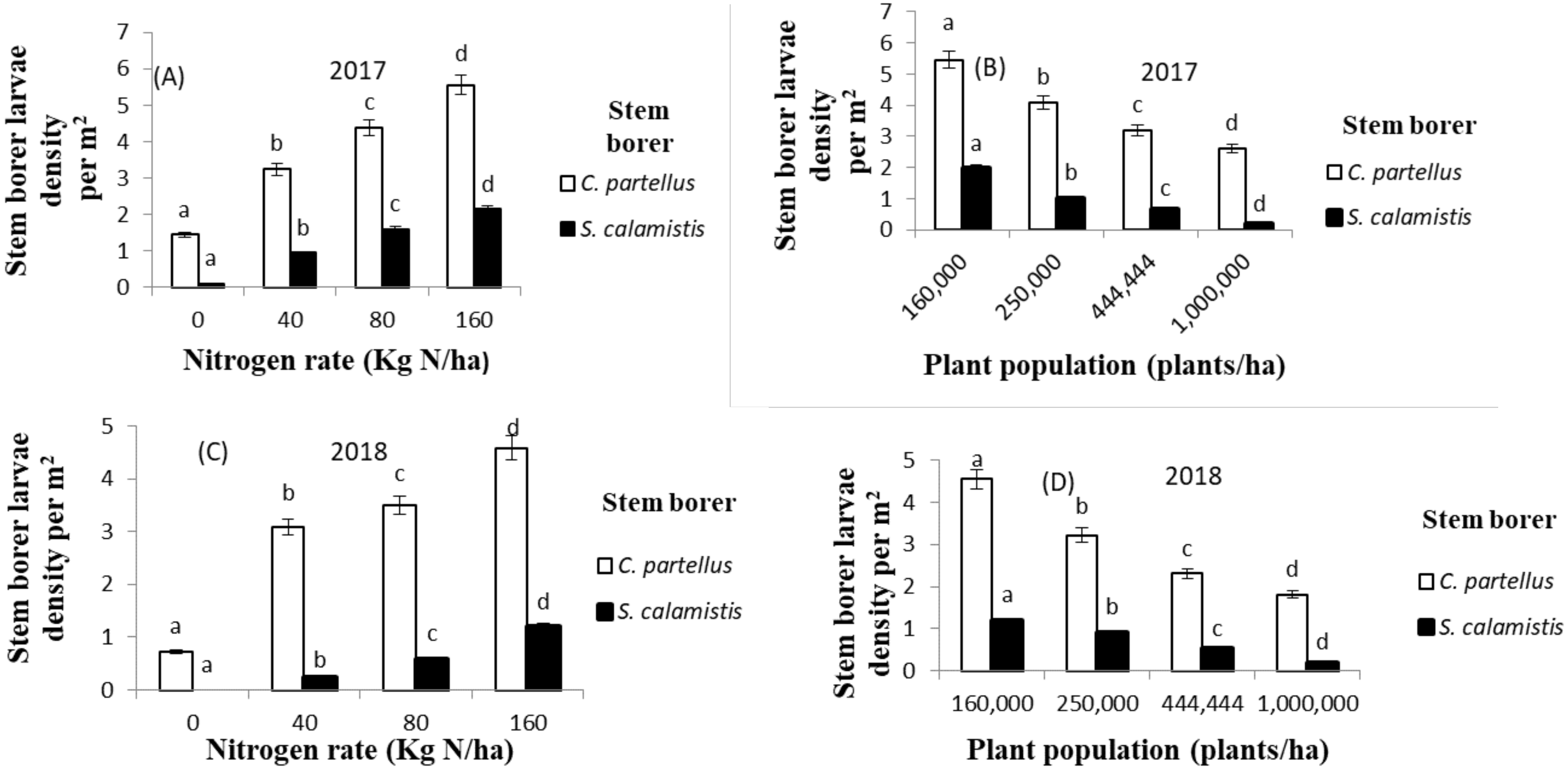


Figure 6.4: **The effects of nitrogen levels (A, C) and plant spacing (B, D) on *C. partellus* or *S. calamistis* larvae density Bars followed by the same letters are not significantly different ($p > 0.05$). Error bars were established based on computed standard errors of each of the parameters.**

6.3.4 Effects of nitrogen fertilizer and plant spacing on rice growth parameters

Rice growth parameters including plant height, number of tillers, stem diameter, chlorophyll content, and succulent content were significantly affected by nitrogen fertilizer and planting density ($P \leq 0.001$) (Table 6.3). These parameters increased as the amount of nitrogen and the plant spacing increased. The highest records for all variables were recorded in plots that received 160 Kg N ha^{-1}, and the lowest were recorded in the control (0 Kg N ha^{-1}) in both 2017 and 2018 cropping seasons. Likewise, the highest records for all crop growth parameters were recorded for wider plant spacing than for close plant spacing. Plots with plant population of 160 000 recorded the highest values, and the lowest values were recorded in plots with planting densities of 1000 000 plants ha^{-1}.

Table 6.3: Effects of nitrogen fertilizer and plant spacing on growth of rice crop

Treatment	Treatment levels	2017 PH	2017 NT	2017 SD	2017 SPAD	2017 SC	2018 PH	2018 NT	2018 SD	2018 SPAD	2018 SC
Nitrogen rates (Kg N/ha)	0	76.43 ±2.85a	7.41±1.52a	2.89±0.15a	34.63±0.95a	49.60±3.68a	78.30±1.87a	7.97±1.55a	2.68±0.15a	32.56±0.98a	47.78± 3.41a
	40	87.88±2.41b	9.54± 1.62b	3.80±0.12b	37.48±0.75b	53.19±3.83ab	90.37±1.19b	10.01±1.62b	3.57±0.12b	35.90±0.74b	62.26±2.82b
	80	88.88±2.68b	11.65±1.85c	3.83±0.13b	41.47±0.72c	57.36±4.13b	90.63±1.3b	12.27±1.77c	3.60±0.13b	39.89±0.71c	68.83±3.05c
	160	95.48±3.11c	12.07±2.18c	3.966±0.14b	43.19±0.77d	66.16±4.61c	95.37±1.45b	12.85±1.97c	3.72±0.14b	41.46±0.75d	73.57±3.36d
Plant population	1000 000	77.52±3.10a	3.18±2.67a	3.136±0.15a	37.34±0.47a	39.04±4.74a	85.18±1.17a	3.69±2.11a	2.91±0.14a	35.73±0.46a	50.98±3.18a
	444 444	86.31b±0.85b	7.12±2.24b	3.406±0.12b	38.89±0.29 b	51.53±3.51b	87.62±0.99a	7.69±1.83b	3.19±0.12b	37.24±0.29b	61.10±2.2b
	250000	90.83±0.79c	13.21±1.17c	3.847±0.06c	40.02±0.12c	64.78±1.5c	90.66±0.59a	13.76±0.99c	3.62±0.06c	38.39±0.11c	66.82±1.58c
	160000	94.02±2.01c	17.15±0.58d	4.102±0.01c	40.51±0.25d	70.96±5.48d	93.20±1.6b	17.96±0.98d	3.872±0.19d	38.86±0.14c	73.54±5.7d
	C.V	1.7	4.3	4.1	0.8	6.8	1.2	3.8	4.2	0.8	2.2
	P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

PH= plant height, NT= number of tillers, SD = Stem diameter, SPAD = Soil plant analysis development, SC= Succulent content, SE = standard error and C.V = coefficient of variation. Means followed by the same letters are not statistically different ($P > 0.05$)

6.3.5 Effect of nitrogen fertilizer and plant spacing on number of panicles

Significant differences were observed during the 2017 cropping season in the number of panicles between nitrogen levels (F = 112.21; df = 3, 94; *P* < 0.001) and different plant spacing (F = 29.16; df =3; *P* < 0.001) and their interaction (F =2.5; df = 9, 94; *P* = 0.001). In the 2018 cropping season, the number of panicles were significantly different between nitrogen levels (F =97.87; df = 3, 94; *P* < 0.001) and plant spacing (F = 24.80; df =3, 94 *P* < 0.001), and their interactions (F =3.70; df = 9, 94; *P* < 0.001) (Fig. 6.4 (A, B, C); Appendix 3). The effect of fertilizer on the number of panicles increased at an increasing rate up to 80 Kg N ha^{-1} nitrogen and at a planting density of 250,000 plants ha^{-1}. Further increases in nitrogen or decreases in planting density; however, had no effect on number of panicles. Thus, the rate of yield gain in terms of panicle number increased at a decreasing rate for fertilizer rates above 80 Kg N ha^{-1}.

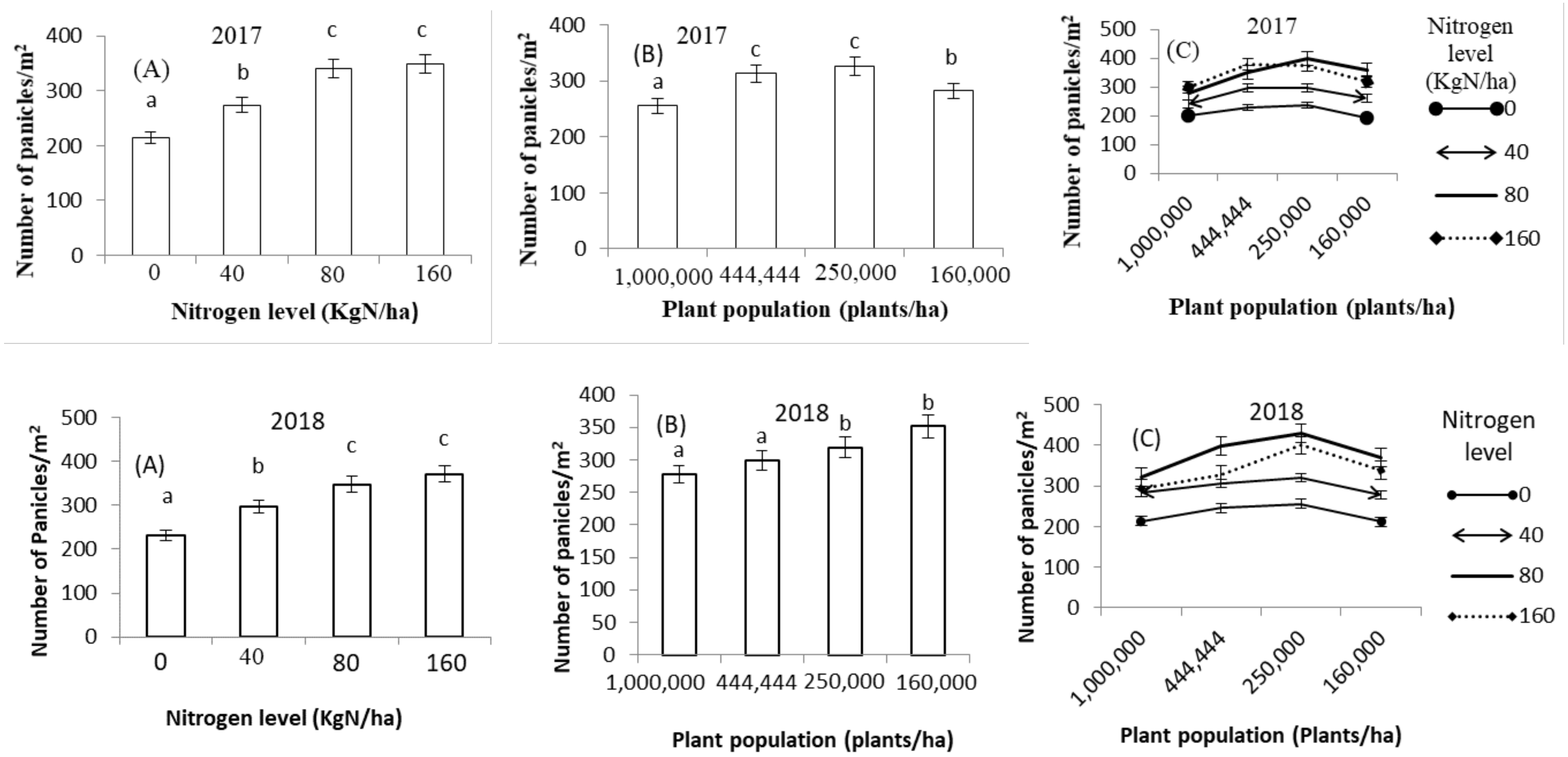


Figure 6.4: The effects of nitrogen and plant spacing on number of panicles

Bars followed by the same letters are not significantly different ($P > 0.05$) based on SNK test. A = Effect of factor A, B = effect of factor B, C = interaction effect of factor A and B.

6.3.6 Effect of nitrogen fertilizer and plant spacing on rice grain yield

There were differences in rice grain yield between different nitrogen levels and spacing in 2017 (N level, $F = 55.15$; df = 3, 94; $P < 0.001$; plant spacing, $F = 35.08$; df = 3, 94; $p < 0.001$), and in 2018 (nitrogen levels, $F = 65.47$; df=3, 94; $P < 0.001$; planting spacing, ($F = 78.78$; df = 3, 94; $P < 0.001$). The interaction effects of nitrogen and plant spacing on rice grain yield were also significant in both years ($F = 4.43$; df =9, 94; $P < 0.001$ in 2017, and $F = 4.04$; df = 9, 94; $P < 0.001$ in 2018 (Fig. 6.5 (A, B, C); Appendix 3). Optimum grain yield was recorded in plots that received 80 kg N ha^{-1} and a planting density of 250,000 plants ha^{-1} in both years (5.63 t ha^{-1} in 2017 and 6.10 t ha^{-1} in 2018). Further increases in nitrogen level did not significantly improve the grain yield. However, there was a decrease in grain yield as plant spacing decreased (i.e. the planting density increased). Seasonal variation in grain yield was also recorded. The grain yield produced in 2018 was higher than the yield produced in 2017 at comparative nitrogen levels and planting densities.

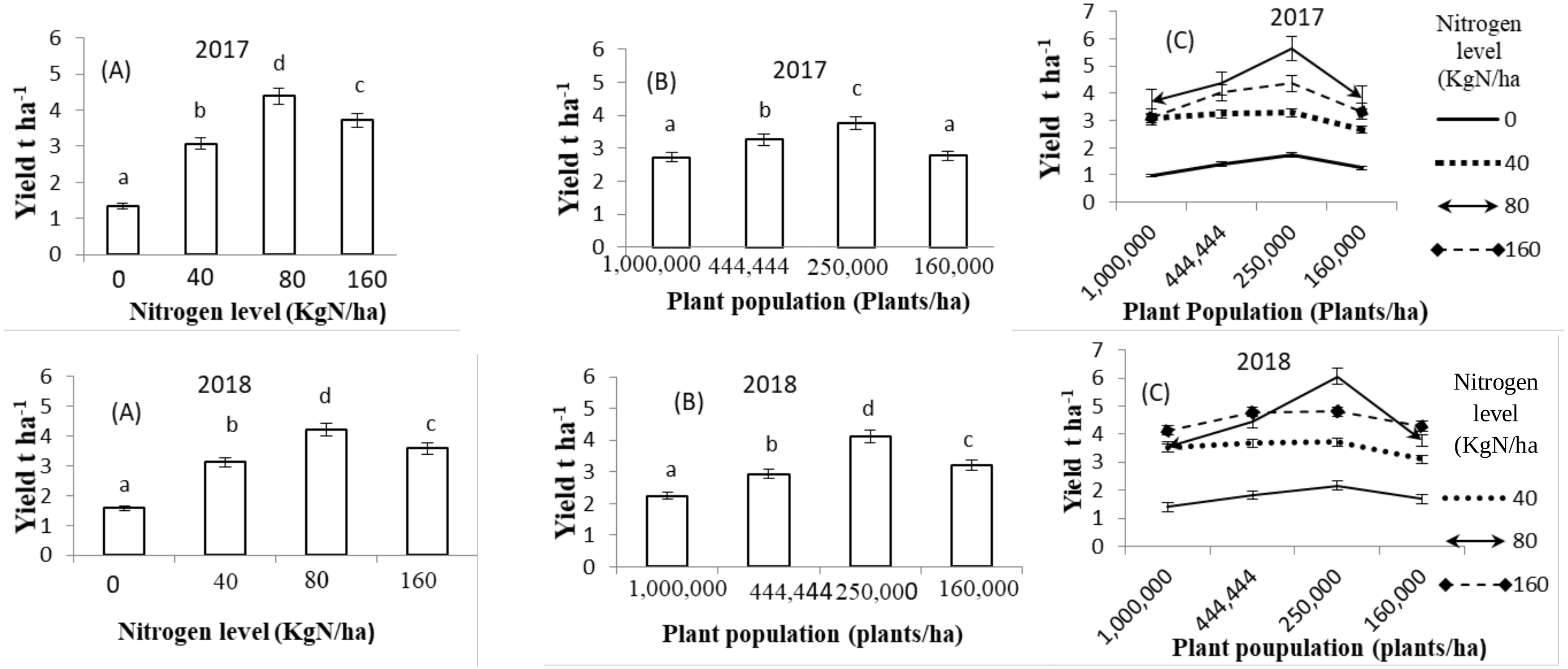


Figure 6.5: The effects of nitrogen and plant spacing on rice grain yield

Bars followed by the same letters are not significantly different ($P > 0.05$) based on SNK test. A = Effect of factor A, B = effect of factor B, C = interaction effect of factor A and B.

6.4 Discussion

The total nitrogen from the study area were similar prior experiment and after experiment. This was due to leaching effects and up take by plant. The findings of this study indicate that the addition of nitrogen fertilizer at different rates affects stem borers, and *C. partellus* and *S. calamistis* injury in rice. Plants grown at high nitrogen levels were more prone to attack by these stem borer species, and hence experienced more damage than plants grown at low nitrogen levels. The addition of nitrogen fertilizer is a useful method for the improvement of plant growth but can predispose them to severe damage by herbivores. The current findings are in line with study on another rice pest by Ogah *et al*. (2005), who found that the addition of nitrogen fertilizer resulted in a significant increase in rice gall midge damage in Nigeria. Similar findings by Veroman *et al*. (2013), reported that nitrogen fertilization affects herbivore host selection, where plants grown with moderate or low nitrogen treatments were less attractive to herbivores than plants treated with high nitrogen levels. The effect of nitrogen fertilizer on pest herbivore interest is not only restricted to chewing insects but is also seen in sucking pests. Studies on cotton (Patel *et al*., 2015) have reported that highest dose of nitrogen fertilizer in BT cotton enhanced the activity of sucking pests, whereas lower incidences of sucking pests were noticed with the application of lower nitrogen doses.

Rice stem borer damage incidences were higher in the dry season (2017) than in the wet season (2018). This could be because only a limited number of farmers cultivated rice during the dry season, and therefore insect pests had to compete for the limited available resources. A similar observation was reported by Mengistu and Selvaraj (2013) in Ethiopia, who found that the incidence and severity of shoot and stalk borer infestations in sugar cane increased in the dry season, compared to the wet season. Interestingly, the lower incidences of damage observed during the wet season may not be due to a lower number of stem borers, but instead to the abundance of the preferred host plants upon which the pests may forage.

This study indicated higher damage incidences in plots with lower planting densities, or wider plant spacing, compared to plots with high planting densities, or narrow plant spacing. The high damage incidence observed at lower planting densities could be explained by the presence of wider spaces, which reduces plant competition for nutrients and other growth resources. This resulted into nitrogen uptake by the plants, which will lead to increases in stem diameter, tenderness, succulent content, and soluble amino acids of the plant, the preferred characteristics for stem borer attack (Elanchezhyan and Arumugiachamy, 2015). Wide plant spacing also increases the number of tillers and the canopy size, which create a favourable microclimate for pest and disease infestation (Ali, 2006). Similar observations were reported by (Mohamed, 2012) for cucumbers, who found that cucumber plants grown in the widest plant spacing treatments were infested with *Bemisia tabaci* Gennadius nymphs at a higher rate than plants planted at closer plant spacing.

Different growth parameters such as plant height, number of tillers, stem diameter, chlorophyll content, and succulent content were found to be affected by the alteration of nitrogen or plant spacing, and positively correlated with stem borer damage incidences. Plant height has been reported to be affected by nitrogen rate and planting densities. Similar findings by Tajul *et al.* (2013) reported that plant height was at its maximum with the highest amount of nitrogen in maize, whereas studies on sorghum (*Sorghum bicolor* (L) Moench) indicated that plant height declined with increased seeding rate (Mobasser *et al.*, 2007; Snider *et al.*, 2012).

The amount of nitrogen fertilizer and plant spacing used had an influence on SPAD values. Tajul *et al*. (2013) reported that SPAD value in maize was highest at the lowest planting density with the highest amount of nitrogen. Moreover, Moro *et al*. (2016) reported high SPAD value in two wider plant spacing treatments (25 cm × 20 cm and 20 cm × 20 cm) than narrow plant spacing treatments of 25 cm × 15 cm, 15 cm × 15 cm, and 30 cm × 10 cm in lowland cultivated rice, which is also in line with the findings of the present study. Stem borer damage incidences were found to increase as SPAD values increased. This is likely due to the increased nitrogen content, which allows the plant to grow more vigorously, and therefore to become more susceptible to stem borer attack, as tissues becomes tender and succulent. Arshad *et al*. (2013) found that increased nitrogen levels in maize led to softer tissues, which eased attack by *Chilo partellus*.

However, nitrogen had a positive influence on number of tillers per plant. Liu *et al.* (2011) reported that the application of nitrogen enhanced tiller production, as it increases the cytokinin content within the tiller nodes and further enhances the germination of the tiller primordium. In contrast, Reuben *et al*. (2016) recommended the use of optimum plant spacing to increase the production of tillers in rice, among other key agronomic characteristic that influence crop growth performance and crop yield. Despite the increase in the number of tillers with increased nitrogen levels and reduced plant spacing, the highest incidence of damage by stem borers were also recorded, suggesting a positive association between tiller numbers and stem borer damage. The increased tiller numbers were probably owing to compensation for the tillers lost because of stem borer damage during the early stages of rice growth. Sylvan (2015) reported that the formation of additional tillers could be promoted by stem borer damage.

In this study, nitrogen and plant spacing were observed to have a positive effect on increased stem diameter. Stem diameter increased as plant spacing increased, or as planting density is reduced. This could be due to a reduction in competition for nutrients, light, and other photo-assimilates with wider plant spacing than with closer plant spacing, which favours the uptake of more nutrients. This corresponds with the report by Snider *et al*. (2012), who observed that stem diameter of sorghum declined as seeding rates and stem density (i.e. planting density) increased. Based on insect herbivore behaviour, larger stem diameters offer more food and a comfortable habitat to burrow and feed, compared to narrow ones, and are therefore preferred by stem borers. This corresponds with the results of studies by John and Warren (1967), Padhi and Sen (2002), and Amin (2011), who reported a correlation between stem diameter and stem borer survival, noting that wild rice with a narrow stem diameter was more resistant to stem borers than cultivated varieties with large stem diameters.

A significant increase in the succulent content of rice with an increase in applied nitrogen rates was also observed. The plants with high succulent content showed the highest incidences of stem borer damage, compared to plants with a low succulent content. This may be because nitrogen has a tendency to reduce the sap flow within the plant tissues, as described by Hu *et al*. (1986), which leads to an increase in the soluble amino acid content of rice sap. The presence of soluble amino acids increases the nutritional values of the sap, which makes the plant more susceptible to insect pest attack. Similar observations were reported by Zhong-xian *et al*. (2004), who found that the water content of rice plants increased significantly and the amount of sap flow reduced significantly, as nitrogen levels increased. However, the findings of this study indicate that there is a significant increase in succulent content with increased plant spacing or reduced planting densities. This could be due to an increased nitrogen uptake in lower planting densities, and is in line with the findings of Lin *et al*. (2011), who found that increasing super-rice planting density in an intensive rice growing system in China caused a significant decrease in nitrogen uptake.

The findings of this study show that nitrogen has a significant influence on grain yield, where the highest yield was obtained at the optimum nitrogen rate of 80 Kg N ha^{-1}. This corresponds with the study by Lacerda and Nascente (2016), who reported that increasing rates of nitrogen up to 50 Kg N ha^{-1} in the topdressing improved grain yields of upland rice grown in no-tillage fields, whereas applications of nitrogen beyond or above that rate did not improve the yield. Likewise, in the current study, increasing the nitrogen rate to 160 Kg N ha^{-1} did not cause any significant change in yield after the optimum yield had been attained at 80 Kg N ha^{-1}. The findings of the current study also indicate the grain yield decreased as planting density increased. This is likely due to competition for limited resources at higher planting densities, which led to a decreased number of tillers and panicles compared with lower planting densities. Moro *et al*. (2016) reported the same observations regarding the influence of plant spacing on rice grain yield. They observed a high grain yield at a plant spacing of 20 cm × 25 cm and 20 cm × 20 cm, compared with the wider plant spacing of 30 cm × 10 cm. This corresponds with the findings of the present study.

Grain yield produced during 2018 was higher than the grain yield produced during the previous year. This could be attributed to the lower damage incidence recorded during the second year, compared to the damage incidence recorded during the first year. The lower value obtained during the first year could be explained by the low rainfall during 2017, compared to that of 2018.

The findings of this study revealed differences in incidences and density of stem borers between wards, with a higher damage incidence in Signali than Mkula or Sanje. This could be due to existence of natural or exotic alternative host species for stem borers. For example, Sanje is located at a higher altitude than Mkula or Signali, and the authors suspect that the low incidence of damage in this location, compared to Mkula and Signali, is the result of the altitude. Certain species of stem borer tend to dominate at high altitudes and others at medium to low altitudes. Ong'amo *et al*. (2006) reported that *Buseola fusca* was dominant at high altitude gradients and *Chillo partellus* at low altitudes, which is in agreement with the findings of the present study. Furthermore, rice is cultivated as a monoculture at Sanje, unlike Mkula and Signali where other crops such as maize and sugar cane are also cultivated. Maize and sugar cane are known to be hosts of stem borer species such as *Chilo* spp and *Sesamia* spp (Nsami *et al*., 2001; Ong'amo *et al*., 2013), the species which have also reported by January *et al*. (2018b) to be present in the study area. Mkula and Sanje are located near the Udizungwa National Park conserved forest, where there is diversity of vegetation and pests. Moreover, the diversity of parasitoids of the stem borers could also be present in this conserved area, which regulates the abundance of stem borer species. This would explain the lower incidence of damage, when compared to Signali. Mailafiya (2011) reported that Poaceae, Cyperaceae, and Typhaceae are important plant families that promote parasitoid diversity and therefore should be grown adjacent to cultivated habitats within the cereal crop ecosystem. These important plant families are also present in the Udizungwa, which is close to the rice cultivation fields of Mkula and Sanje.

6.5 Conclusion

This study demonstrated that incremental doses of nitrogen fertilizer increased damage and infestation of rice by stem borers, *C. partellus* and *S. calamistis*. The application of nitrogen fertilizer beyond 80 Kg N ha^{-1} did not result in any added advantage. Similarly, reducing rice planting density to 160 000 plants ha^{-1} significantly increased damage by pests and decreased grain yield. Generally, the interactions of nitrogen and planting density did not produce any significant effect on incidences and densities of stem borers.

The results of this study therefore suggest that *Oryza sativa* 'TXD 306' should be cultivated with a plant spacing of 20 cm × 20 cm and 80 Kg N ha-^{1} topdressing to obtain optimum yields and to reduce losses that may be incurred due to stem borer infestation. Further studies should examine the effect of plant spacing and nitrogen on damage incidences of different rice varieties which are commonly grown and preferred by farmers.

Acknoledgements

We are gratefully acknowledge farmers and extension officers in all wards where this study was conducted for their support. We also gratefully acknowledge the financial support of the UK' Department for International Development (DFID); the Swedish International Development Cooperation Agency (SIDA); the Swiss Agency for Development and Cooperation (SDC); and the Ethiopian and the Kenyan Government.

References

Ali, S. M. D. (2006). Effect of plant spacing on the incidence of major insect pests and their natural enemies in four rice varieties. Thesis for the Award of Masters Degree of Entomology at Bangladesh Agriculture University, Bangladesh. 68pp.

Amin, M. E. H. (2011). Effect of different nitrogen sources on growth, yield and quality of fodder maize (*Zea mays* L.) *Journal of the Saudi Society of Agricultural Sciences* 10: 17 - 23.

Amuri, N. A., Mhoro, L., Mwasyika, T and Semu, E. (2017). Potential of soil fertility management to improve essential mineral nutrient concentrations in vegetables in Dodoma and Kilombero, Tanzania. *Journal of Agricultural Chemistry and Environment* 6: 105 - 132.

Arshad, M. J., Freed, S., Akbar, S., Akmal, M and Gul, H. T. (2013). Nitrogen fertilizer application in maize and its impact on the development of *Chilo partellus* (Lepidoptera: Pyralidae). *Pakistan Journal of Zoology* 45(1): 141 - 147.

Baidoo, P. K. (2004). The role of silica and nitrogen in resistance of maize to stem borers. *Journal of Science and Technology* 24: 1.

Banwo, O. O. (2002). Management of major insect pests of rice in Tanzania. *Plant Protection. Science* 38 (3): 108 – 113.

Doberman, A and Fairhust, T. (2000). *Rice nutrient disorders and nutrient and nutrient management*. International Rice Research Institute. Potash and Phosphate Institute of Canada and International Rice Research Institute, Singapore and Los Baños. 203pp.

Elanchezhyan, K and Arumugiachamy, S. (2015). Evaluation of medium duration germplasm against yellow stem borer, *Scirpophaga incertulas* Walker in rice. *Biotic Environment, formerly Insect Environment* 21: 2 - 3.

Goswami, B., Maki, G. S and Saikia, U. S. (2006). Effects of few important climatic factors on phenology, growth and yield of rice and wheat. A Review. *Agricultural Revew* 27(3): 223 – 228).

Hu, J. Z., Lu, Q. H., Yang, J. S., Yang, L. P and Gao, N.Y. (1986). Effects of fertilizer and irrigation on the population of main insect pests and the yield of rice. *Acta Entomology* 29(1): 49 – 54.

Indike, A. (2002). Analysis of pest management methods used for rice stem borer (*Scirpophagaincertulas*) in Sri Lanka based on the concept of sustainable development. Thesis for Award of Masters Degree at Lund University, Maharagama, Colombo, Sri Lanka. 377pp.

January, B., Rwegasira, G. M and Tefera, T. (2018a). Farmers' perceptions of rice production constraints and stem borers management practices in Tanzania. *Journal of Agricultural Science* 10: 6.

January, B., Rwegasira, G. M and Tefera, T. (2018b). Lepidopteran stem borer species abundance and associated damages on irrigated Kilombero low land rice ecosystem in Tanzania. *Journal of Entomology* 15: 28 - 35.

John, H. M and Warren, H. L. (1967). *Pasture and pasturage*. In: Methew, J and Jack, S. S (Eds). Principle of field crop production. 257 – 258pp.

Kato, Y., Abe, J., Kamoshita, A and Yamagishi, J. (2007). Varietal differences in stem diameter and rooting number of phytomers in conjunction with root system development of field-grown rice (*Oryza sativa* L.). *Plant Production Science* 10 (3): 57-36.

Lacerda M. C and Nascente, A. S. (2016). Effects of row spacing and nitrogen topdressing fertilization on the yield of upland rice in a no-tillage system. *Acta Scientiarum Agronomy Maringa* 38(4): 493 - 502.

Landon, J. R. (1991). *Booker tropical soil manual*. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. John Wiley and Sons: New York. 450pp.

Leonard, A. (2015). Incidences and spatial distribution of stem borers in rice crop in Kahama District. Dissertation for Award of Msc. Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 66pp.

Litsinger J. A. (1994). Cultural, mechanical and physical control of rice insects. In: Heinrichs, E. A. (ed.). Biology and management of rice insects. International Rice Research Institute, Philippines. 779pp.

Lin, Y., Ding, Y. F., Wang, Q. S., Meng, D. X and Wang, S. H. (2011). Effects of nitrogen and 6-benzylaminopurine on rice tiller bud growth and changes in endogenous hormones and nitrogen. *Crop Science* 51: 786 – 792.

Mailafiya, D. M. (2011). Importance of wild host plants for stem borer parasitoid diversity and control of parasitism in cereal cropping ecosystems in Kenya. *International Journal of Biodiversity Science, Ecosystem Services and Management* 7: (1) 12 - 19.

Mbaga, H. R., Msanya, B. M and Mrema, J. P. (2017). Pedological Characterization of Typical Soil of Dakawa Irrigation Scheme, Mvomero District, Morogoro Region, Tanzania. *International Journal of Current Research in Bioscience and Plant Biology* 4(6): 77 - 86.

Mengistu, L and Selvaraj, T. (2013). Diversity of sugarcane borer species and their extent of damage status on cane and sugar yield in three commercial sugarcane plantations of Ethiopia. *International Journal of Agricultural Technology* 9(6): 1461 - 1473.

Mghase, J., Shiwachi, H., Nakasone, K and Takahashi, H. (2010). Agronomic and socio-economic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research 5*(2): 150 - 158.

Mobasser, H. R., Delarestaghi, M. M., Khorgami, A., Tari, B. D and Pourkalhor, H. (2007). Effect of planting density on agronomical characteristics of rice (*Oryza sativa* L.) varieties in North of Iran. *Pakistan Journal of Biological Sciences* 10: 3205 - 3209.

Mohamed, A. (2012). Impact of planting dates, spaces and varieties on infestation of cucumber plants with whitefly, *Bemisia tabaci* (Genn.). *Journal of Basic and Applied Zoology* 65 (1): 17 - 20.

Moro, B. M., Roland, N. I and Martin, E. A. (2016). Effect of spacing on grain yield and yield attributes of three rice (*Oryza sativa L.*) varieties grown in rain-fed lowland ecosystem in Ghana. *International Journal of Plant and Soil science* 9(3): 1 - 10.

Msanya, B. M., Kaaya, K. A., Araki, S., Otsuka, H and Nyadzi, I. G. (2003). Pedological characteristics, general fertility and classification of some benchmark soils of Morogoro, Tanzania. *African Journal of Science and Technology* 4: 701 – 731.

Nsami, E., Mgoo, V. H and Omwega, C. O. (2001). Distribution and species composition of cereal stem borers in the eastern zone of Tanzania. *Insect Science Application* 4: 347 - 351.

Nwilene, E. F., Nacro, S., Tamò, M., Menozzi, P., Heinrichs, E. A., Dakouo, A. H. D., Adda, C and Togola, A. (2013). Managing insect pests of rice in Africa. CAB International, UK. 229 – 240pp.

Ogah, E.O. (2013). Evaluating the impact of new rice for Africa (NERICA) in the management of rice stem borers. *Journal of Science International* 1(5): 160 - 166.

Ogah, E. O., Echezona, B. C and Umeh, E. D. N. (2005). Effects of N-fertilization and spacing on African rice gall midge,*Orseolia oryzivora* Harris and Gagne in Sub-humid area of Southern Nigeria. *Journal of Agriculture, Food, Environment and Extension* 4(2): 15 - 18.

Ong'amo, G. O., Le Ru, B. P., Dupas, S., Moyal, P., Calatayud, P. A and Silvain, J. F. (2006). Distribution, pest status and agro-climatic preferences of lepidopteran stem borers of maize in Kenya. *Annales de la Société Entomologique de France* 42(2): 171 - 177.

Ong'amo, G. O., Le Ru, B. P., Dupas, S., Moyal, P., Calatayud, P. A and Silvain, J. F. (2013). The role of wild host plants in the abundance of lepidopteran stem borers along altitudinal gradient in Kenya. *Annales de la Société entomologique de France* (N.S.) 42: 363 - 370.

Padhi, G and Sen, P. (2002). Evaluation of wild rice species against yellow stem borers (*Scirpophata insertulas* Walk. *Journal of Applied Zoology Research* 13: 147 – 148.

Patel, C. K., Bharpoda, T. M., Zala, M. B and Shah, K. D. (2015). Impact of plant spacing and nitrogenous fertilizer on incidence of sucking pests in Bt cotton. *International Journal of Plant Protection* 8(1): 34 - 40.

Pathak, M and Khan, Z. R. (1994). *Insect Pests of Rice*. International Centre of Insect Physiology and Ecology. International Rice Research Institute. Manila. Philipins. 5 – 16pp.

Prasad, S. S and Gupta, A. K. (2012). Compatibility of new insecticides and fungicides against stem borer and leaf blast on semi-deep water rice. *Crop Research* 43(3): 197 - 200.

Rami, K., Overholt, W. A., Khan, Z. R and Polaszek, A. (2002). Biology and management of economically important lepidopteran cereal stem borers in Africa. *Annals Revew of Entomology* 47: 701 – 731.

Ranasinghe, M. A. S. K. (1992). *Paddy pests in Sri Lanka.* Science education series No.30. Natural resources energy science authority of Colombo (Sri Lanka). 47 – 59pp.

Reuben, P., Kahimba, F. C., Katambara, Z., Mahoo, H. F., Mbungu, W., Mhenga, F., Nyarubamba, A and Maugo, M. (2016). Optimizing plant spacing under the systems of rice intensification (SRI). *Agricultural Sciences* 7: 270 - 278.

R version 3.3.1. (2016). The R foundationfor statistical computing platform: x86_64- w64-mingw32/x64 (64-bit).

Sarwar, M. (2011). Effects of Zinc fertilizer application on the incidence of rice stem borers (*Scirpophaga*species) (Lepidoptera: Pyralidae) in rice (*Oryza sativa* L.) crop. *Journal of Cereals and Oilseeds* 2(5): 61 - 65.

Sarwar, M. (2012). Effects of potassium fertilization on population build-up of rice stem borers (lepidopteron pests) and rice (*Oryza sativa* L.) yield. *Journal of Cereals and Oil seeds* 3(1): 6 - 9.

Showler, A. T. (2004). Weeds in crop systems for pest suppression. In: Capinera, J. L (ed.) Encyclopedia of Entomology Volume 3. 1st edition. Hingham, MA: Kluwer Academic Publishers. 31 - 35pp.

Singh, P., Singh, R., Dhaka, S. S., Kumar, D., Kumar, H and Kumar, N. (2015). Bioefficacy of insecticides and bio-pesticides against yellow stem borer, *Scirpophaga incertulus* (walk.) and their effect on spiders in rice crop. *South Asian Journal of Food and Technology Environment* 1(2): 179 - 183.

Snider, J. L., Raper, R. L and Schwab, E. B. (2012). Effects of row spacing and seeding rate on biomass production and plant stand characteristics of non-irrigated photoperiod-sensitive sorghum (*Sorghum bicolor* (L.) Moench). *Industrial Crops and Products* 37: 527 - 535.

Suresh, K., Bhaskaran, R. K. M., Santhilkumaran, S., Rajaval, M and Shanti, K. (2009). Effect of organic sources of nutrient on management of sucking pest of *Cassia angustifolia*. *Journal of Plant Protection Science* 17: 32 - 36.

Sylvain, N. M., Manyangarirwa, W., Tuarira, M. (2015). Effect of lepidopterous stem borers, *Busseola fusca* (Fuller) and *Chilo Partellus* (Swinhoe) on maize (*Zea mays* L) yield: A Review. *International Journal of Innovation Research and Development* 4: 10.

Tajul, M. I., Alam, M. M., Hossain, S. M., Naher, K., Rafii, M. Y and Latif, M. A. (2013). Influence of plant population and nitrogen-fertilizer at various levels on growth efficiency of maize. *The Scientific World Journal* 2: 19 - 30.

Touhidur, R., Khalequzzaman, M and Ataur, M. R. K. (2004). Assessment of infestation and yield loss by stem borers on different rice varieties. *Journal of Asia-Pacific Entomology* 7(1): 89 - 95.

United Republic of Tanzania. (2014). *Expanding rice production project* (ERPP). Integrated pest management plan. 53pp.

Veromann, E., Toome, M., Kännaste, A., Kaasik, R., Copolovici, L., Flink, J., Kovács, J., Narits, L., Luik, A and Niinemets, U. (2013). Effects of nitrogen fertilization on insect pests, their parasitoids, plant diseases and volatile organic compounds in *Brassica napus*. *Crop Protection Journal* 43: 79 – 88.

Wale, M., Schulthess, F., Kairu, E and Omwega, C. O. (2006). Cereal yield losses caused by lepidopterous stemborers at different nitrogen fertilizer rates in Ethiopia. *Journal of Applied Entomology* 130(4): 220 – 229.

Yuan, Z., Cao, O., Zhang, K., Syed, S. T., Tian, Y., Zhu, Y., Cao, W and Liu, X. (2016). Optimal leaf positions for SPAD meter measurement in rice. *Front Plant Science* 7: 719.

Zhong-xian, L., llareal, S. V., Xiao-ping, Y., Heong, K. L and Cui, H. (2004). Effect of nitrogen on water content, sap flow and tolerance of rice plants to brown planthopper, *Nilaparvata lugens*. *Rice Science* 11(3): 129 – 134.

CHAPTER SEVEN

7.0 GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

This PhD study was carried out to establish the role and significance of rice stem borers as pests of rice crop in irrigated low land rice ecosystems in Tanzania; and to evaluate the effectiveness of some management options against the pest. Two rice stem borers, *Chilo* sp and *Sesamia calamistis* were found to be major problem in Kilombero valley. There were variation in sites where Sanje and Mkula were found to have low stem borer incidences as compared to Signali. A parasitoid, *Cotesia flavipes* was found to exist in all study areas which is an important biological control of these stem borers. Two fungi based biopesticides; *Metarhizium anisopliae* and *Beauveria bassiana* at the rate of 1ml/l and botanicals, *Derris elliptica* and *Neouratanenia mittis* at the rate of 10mil/l were found to be effective agaist rice stem borer which contributed to stem borer mortality rates of 50 - 78%. Application of Nitrogen fertilizer at the rate of 80 Kg N ha^{-1} and spacing of 20 cm x 20 cm were found to be optimum for reduction of incidences of stem borers with increased rice yield.

7.2 Recommendations

Based on the findings of this study, the following are the recommendations;

1. Lamda cyhalothrin was not effective against stem borer control. Efforts should be made to educate farmers on appropriate dosage to apply and how to use application protocols.

2. The two botanicals, *D. elliptica* and *N. mitis* have been proved to be effective in the control of stem borers. Therefore efforts should be made to explore standardization and packaging for farmers to get them at easy.

3. The two fungi based biopesticides; *M. anisopliae* and *B. bassiana* have proved to be effective against stem borer. Preliminary of use should be by exploring the locally available biopesticides and of low cost.

4. Variation in nitrogen rates and spacing was proven to be beneficial against stem borer problem. Since this was evaluated by considering only one variety, future studies should consider many commonly grown varieties for the benefit of the farmers.

APPENDICES

Appendix 1: Questionnaire of field survey for rice stems borers

SECTION 1: METADATA

Introductory and consent statement:

"Dear Sir/Madam, I work for the ++++++. We are conducting a survey to study farmers' rice insect pests' knowledge and their management practices in your village. Your response to these questions would remain **anonymous**. Taking part in this study is voluntary. If you choose not to take part, you have the right not to participate and there will be no consequences. Do you and your family consent to provide information? 1 = yes, 0 = No. Thank you for your kind co-operation".

	NAME
ENUMERATOR ID	
NAME OF WARD	
NAME OF VILLAGE	

SECTION 2: LOCATING HOUSEHOLD AND OBTAINING CONSENT

No.	**QUESTIONS**	**CODES/RESPONSES**	**GO TO**
[INTERVIEWER: YOUR FIRST JOB IS TO LOCATE THE HOUSEHOLD AND THE FARMER THAT WAS IDENTIFIED IN THE LIST TO BE INTERVIEWED. IF YOU CANNOT FIND THE HOUSEHOLD OR THE FARMER IS NO LONGER IN THE VILLAGE, THESE QUESTIONS WILL HELP TO DETERMINE WITH WHOM (OR IF) THE INTERVIEW WILL BE CONDUCTED.			
1	**WERE YOU ABLE TO LOCATE THE HOUSE?**	No……………………………………………………………..…...0 Yes…………………………………………………………..…....1	**> Q6** **> Q2**
2	Please write down the correct **latitude of the housed**.	**[USE GPS DEVICE]:** ________________________________	
3	Please write down the correct **longitude of the house**.	**[USE GPS DEVICE]:** ________________________________	
4	**DOES THE FARMER (HE/SHE) CONSENT TO BEING INTERVIEWED?**	No, rejects interview……………………………………………...0 Yes, accepts interview……………………………..……......1	**> STOP** **> Q5**
5	**Name of farmer**	**(WRITE DOWN NAME):**___________________________	

SECTION 3: DEMOGRAPHIC INFORMATION

No	**QUESTIONS**	**CODES/RESPONSES**	**GO TO**
[INTERVIEWER: SAY TO THE FARMER: I WOULD FIRST LIKE TO ASK YOU QUESTIONS ABOUT YOURSELF AND YOUR FAMILY.			
1	What is your age?	[___|___] Years	
2	Male or female? **[MAY NOT NEED TO ASK]**	Male……………………………………………………………...1 Female…………………………………………………………...2	
3	Has the farmer ever attended school?	No……………………………………………………………………0 Yes……………………………………………………………...1	**-> Q5** **> Q4**
4	What is your level of education	Primary school…………………………………………...…1 Secondary school………………………………………………2 College education…………………………………………..…….3	

No	QUESTIONS	CODES/RESPONSES	GO TO
		Others……………………………………………….….(specify)	
	How many family members live in your house (live under same roof)?		
5	… Number of male members?	[___|___]	
	Their age?	[___|___][___|___][___|___][___|___][___|___][___|___]	
6	… Number of female members?	[___|___]	
	Their age?	[___|___][___|___][___|___][___|___][___|___][___|___]	
7	How many of these family members work or are able to work? **(Q12 CANNOT BE GREATER THAN Q12 AND Q13)**	[___|___]	
8	What is your marital status	Single or never married…………………………………….……..1 Married (legal or not)……………………………...……...…2 Widow/widower……………………………..……..……..…3 Separated/Divorced…….…………………………….….…….4	

SECTION 4: RICE PRODUCTION

No	QUESTIONS	CODES/RESPONSES	GO TO
[INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT THE RICE YOU PRODUCED			
1	How many acres of rice do you own?	Less than 3 …………………………………….……………1 Four to six…………………………………………….….…..2 Seven to ten……………………….………………….……....3 More than 10…………………….………………….………..4	
2	During the past 12 months what was the total value of the Rice you harvested?	……………………….……bags of…...……………….…….….kg	
3	What proportion of your Rice production do you consume in your household?	None…………………………………………...…….….……1 Some, but less than half…………..…………………………...2 More than half……………………….……………………...3	
4	What proportion of your family's income is from selling Rice?	None………………………………..…….…………………....1 Some, but less than half..........…..…….………………………2 More than half …………………………………………..……..3	

SECTION 5: PESTS and PEST MANAGEMENT OF RICE CROP

No	QUESTIONS	CODES/RESPONSES	GO TO
INTERVIEWER: SAY TO THE FARMER: NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT YOUR RICE PEST MANAGEMENT LAST YEAR.			
1	**DID YOU GROW RICE LAST YEAR?**	No.………..………………………….……..…………...……0 Yes.……………..…………………………………………...…..1	
2.	**What were the main constraints you faced in rice production (start from the most to the least constraint)**	………………………………………………………..…...………… ……………………………………………..…...………………… …………………………………….......…………………………… ……………………......……………..……	
a	How severe were rice insect pests last year?	None……………………………………………...…………0 Low……………………………………………………..……..1 Medium……………………….………………………..………2 High…….………………………………………………..…..3	
b	What was your **worst** insect pest last year?	Specify:____	
c	How severe were your rice insect	None……………………………………………………...…0	

No	QUESTIONS	CODES/RESPONSES	GO TO
	pest last year?	Low…………………………………………………..………..1 Medium……………………………………………..………2 High…………………………………..………………..3	
d	What are the major insect pests affecting rice?	Stem borers ……………………………………..…………..1 African rice gall midge ……………………………….………2 Grasshoppers…………………………………………..………3 White flies…………………………………………………..4 Leafrollers …………………………………………………….5 Other,specify …………………………………...………..…6	
e	What practices, if any, did your household use to control these insect pests? **(CIRCLE ALL THAT APPLY)**	Burning crop residue…………………………..………………1 Remove and bury infected plants…………………...….……2 Use of insecticides…………………………….……………….3 Split application of N fertilizer……………………………4 Others……………………………….………………(Specify) None………………………………………………...………0	
f	List the names of all chemical inputs which was used in management of rice insect pests	____ ____ ______________________________	

SECTION 6: FARMERS' PERCEPTION ON RICE STEM BORER

(a) Do you know the rice stem borer? (1) Yes, (2) No

(b) If yes, what is its local name? …………………..

(c) Has rice stem borer ever affected your farm? (1) Yes, (2) No (If yes, answer the following questions)

(d) What are the symptoms? (1) Dead heart, (2) White head, (3) Dead heart and white head

(e) What insect pest is more destructive in rice production? (1) Stem borer, (2). Others (specify), (3) None

(f) Have you ever realized rice stem borer occurrences in other farms? (1) Yes, (2) No

(g) If yes indicate the month, year and distance of the farm from your farm.

Month	Year	Distance from your farm (see code sheet)

h) Does the borers affect the rice crop in your farm throughout the growing season? (Please tick as appropriate)

(1) Yes ☐ (2) No ☐

(i) If No, Indicate which month(s) of the year the disease is prevalent

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec

Appendix 2: Mean squares and significance tests of the effect of fungi based biopesticides and botanical extracts in rice stem bores management

Source of Variation	df	PH	NT	DHC	WHC	DH	WH	NP	NWH	GW	YL
Replications	3	3.053	8.84	13.41	3.05	1664.9	90.7	60.4	0.5584	0.57	57.86
Treatments	5	144.89**	7.83^{ns}	167.801**	144.89**	1432.70**	1879.70**	2274.80**	10.45**	0.51^{ns}	1713.68**
Error	15	3.429	7.585	6.671	3.429	178	157.4	276	0.3916	0.2747	33.53
Total	23										

df = degrees of freedom, PH= plant height, NT= number of tillers, DHC = dead heart incidences, WHC = white head incidences, DH = number of dead head, WH= number of white head, NP = number of panicles, NWH = number of white head, GW = 1000 grain weight, YL = yield losses.
**Significant difference at 0.01 probability level and ns = non-significant difference at 0.05

Appendix 3: Mean squares and significance tests of the effect of location, spacing and different levels of nitrogen fertilizer on rice growth variables, damage incidences, stem borer larvae density, yield and yield components

Year	Factor	df	DHI	WHI	*C. partellus*	*S. calamistis*	SD	C.C	WC	GY
2017	Location (L)	2	6.10**	5.42**	125.08**	15.19**	0.63**	27.08**	687.89**	10.15**
	Nitrogen rate (N)	3	10.75**	5.07***	107.93**	24.94**	8.98**	574.83**	3424.72**	61.41**
	Spacing (S)	3	31.78**	12.82**	54.72**	14.27**	7.99**	91.39**	3791.46**	8.44**
	L X N	6	0.30ns	0.14ns	11.23ns	1.66ns	0.05ns	2.22ns	146.29ns	0.17ns
	L X S	6	0.50ns	0.06ns	1.00ns	0.94ns	0.04ns	1.86ns	167.26ns	0.58ns
	N X S	9	0.83ns	0.4ns	3.27ns	1.9ns	0.36**	7.76**	67.22**	1.07**
	L X N X S	18	0.20ns	0.17ns	0.84ns	0.57ns	0.02ns	1.32ns	20.91ns	0.26ns
	Error	94	0.51	0.4	0.96	0.36	0.07	2.01	25.2	0.24
2018	Location (L)	2	8.09**	6.058**	123.382**	7.55**	0.69*	24.17**	787.11**	2.02**
	Nitrogen rate (N)	3	13.63**	5.26**	95.39**	9.6181**	16.05**	573.71**	3832.43**	45.54**
	Spacing (S)	3	34.46**	15.58**	52.50**	7.91**	4.89**	91.20**	7070.38**	21.69**
	L X N	6	0.38ns	0.12ns	12.58ns	1.3264ns	0.10ns	2.57ns	155.3ns	0.27ns
	L X S	6	0.64ns	0.06ns	0.826ns	0.826ns	0.10ns	1.904ls	197.21ns	0.12ns
	N X S	9	0.32ns	0.37ns	3.85ns	2.2292ns	0.34*	7.72**	41.75**	1.11**
	L X N X S	18	0.203ns	0.140ns	1.132ns	0.51ns	0.092ns	1.37ns	29.82ns	0.11ns
	Error	94	0.51	0.51	1.22	0.1568	0.028	1.99	19.2	0.28

Notes: df=degrees of freedom; DHI = dead heart incidences; WHI= white head incidences; SD = Stem diameter; WC = water content; C.C= Chlorophyll content; GY = Grain yield; L = location; N= Nitrogen level and S = Spacing ** Highly Significant ($p \leq 0.001$); *Significant ($p \leq 0.05$) probability level and ns = none significant ($p >$ 0.05).