

MAKERERE



UNIVERSITY

**ROLE OF INTERCROPPING AND ASSOCIATED GRASSES ON OCCURRENCE OF
LEPIDOPTERAN STEM BORERS AND THEIR NATURAL ENEMIES ON MAIZE**



BY

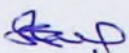
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**A THESIS SUBMITTED TO THE DIRECTORATE OF RESEARCH AND
GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE AWARD OF THE DEGREE OF
MASTER OF SCIENCE IN CROP SCIENCE OF
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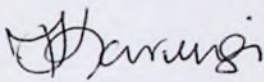
DECLARATION

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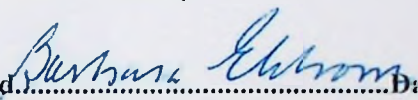
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DEDICATION

This thesis is dedicated to my dear sons Dalton Benjamin Gayi, Davinche Usher Gayi, My daughters Darlin Agness Nagayi, Denise Sasha Nagayi, Daniella Teddy Nagayi and finally to my wife Namaweje Agness Gayi.

For the love and support you accorded me all through this study

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ABSTRACT

The study was conducted in 2012 and 2013 in Kiryandongo district, western Uganda in Bweyale and Diika sub counties. Study sites were selected basing on cropping system and proximity to a grassland with wild grass species within a radius of 500m away from the maize field. A total of 28 maize fields were used in 2012, fourteen maize fields from each Sub county, 7 under monocrop system and 7 under intercrop system. In the first season of 2013 (2013A), 36 maize fields were used 18 maize fields per sub county, 9 under monocrop system and 9 under intercrop system. Each selected field was sampled twice at vegetative stage, once at tasselling stage and once at physiological maturity in each cropping season. The study revealed that *Chilo partellus* was the most dominant species, accounting for over 75% of the total borer species collected, followed by *Busseola fusca*. With regard to parasitoids, *Cotesia flavipes* was the most abundant in the area with *Cotesia sesamea* occurring in very low numbers and was considered negligible. Intercropping maize with non-host crops reduced *Chilo partellus* larval infestation and supported higher *Cotesia flavipes* parasitoids numbers compared to the monocropped fields. The highest mean stemborer incidence was recorded in the vegetative growth stage of maize.

The survey showed 12 grass species surrounding maize fields; *Hyperrhenia rufa*, *Pennisetum purpureum*, *Pennisetum polystachion*, *Rottobolia cochiliensis*, *Thameda triandra*, *Panicum maximum*, *Cynodon dactylon*, *Eleusine coronaca*, *Sorghum vesicolar*, *Cyperus scariosus*, *Saccharum officinarum* and *Heteropogon contortus* as important hosts/refugia for stemborers and their parasitoids albeit to varying levels. *Chilo partellus* preferred maize and *Pennisetum*, whereas *Busseola fusca* was most abundant on maize and *Saccharum officinarum*. *Cotesia flavipes* was most abundant on borers found on *Saccharum officinarum*.

This study showed that cropping system influenced occurrence of the major stem borers and the larval parasitoid on maize with monocrops consistently having higher occurrence of both *Chilo partellus* and *Busseola fusca* and lower counts of *C. flavipes*. On the other hand maize intercrop system consistently increased *C. flavipes* and reduced stem borer occurrence on maize as well as yield. Secondly, there were variable levels of occurrence of maize stem borers and *C. flavipes* parasitoid on maize and grasses. Nevertheless, maize was the most favoured hosts of both *Chilo partellus* and *Busseola fusca*.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Maize (*Zea mays L.*), is the second most important source of carbohydrates after cassava in Sub Saharan Africa (FAO, 2015). The introduction of maize dates back to the 16thC by the Portuguese traders from Latin America. Maize is believed to have originated from the present day Mexico (Polaszek and Khan, 1998), with historical evidence indicating that by the end of the 15thC, maize was already an important food crop in Mexico and Peru. Its introduction in East Africa was most likely by the Portuguese, and was first recorded in Uganda in 1882 as a minor crop. As such, the crop is considered as a relatively recent introduction in comparison to more traditional African cereals such as millet and sorghum in terms of both agro ecology and insect plant interactions although it has existed in Africa for over 300 years and has overtaken them in importance (Polaszek and Khan, 1998). Since the 1980s, many countries in sub-Saharan Africa have remained net importers of maize. This is attributed to a rapidly expanding population and stagnating yields over the years (FAO, 2015). In spite of this, it is forecasted that by the year 2020, the global demand for maize will have grown by 45% of which 72% will be in developing countries while only 18% in the industrialized nations (James, 2003). In order to deal with the surging demand, new methods of production need to be sought while reinforcing the existing ones to better manage the complex of problems facing maize farmers in tropical Africa (FAO, 2002).

In Uganda, maize is an important component of most farming systems and the diet of many people providing over 40% of the population's calorie requirements with an annual consumption of about 23 kg per capita per year (NARO, 2002). After the uncertainty of coffee prices, maize became the most important source of income for the people of Uganda serving as an agricultural export crop to both rural and urban communities, with informal exports equivalent to 14-20% of total production (Magnay, 2004). The major maize producing areas include: Iganga, Kumi, Sironko, Kiboga, Masindi, Kiryandongo, Kamwenge and Kapchorwa (NARO, 2002). In Uganda maize production has averaged 1,272,000 tonnes with an average grain yield of 1.4 t ha⁻¹ which is still considerably less than the 5.1 t ha⁻¹ in developed countries such as USA (FAOSTAT,

2009). The growth in maize production in Uganda has been primarily due to expansion of area planted than improvement in yield per hectare (Kasenge *et al.*, 2001).

The major constraints to maize production in Uganda are pests and diseases which reduce pre and post-harvest quality and quantity of maize; depletion of soil fertility and erratic rainfall (Sserunkuuma *et al.*, 2001). Among the maize pests, lepidopterous stemborers are the most notorious in sub Saharan Africa. In East Africa, the major species are *Busseola fusca* (Fuller), *Sesamia calamistis* (Hampson), *Eldama saccharina* (walker) and *Chilo partellus* (Swinhoe) (Kauma, 2000; Munyeko *et al.*, 2003). Maize production in Uganda is largely rain fed with the largest proportion grown by smallholder farmers. The implication is seasonal productivity depending on rainfall availability, followed by a dry period after crop harvest. This seasonal productivity could mean reduction in stemborer pest population after crop harvest due to the absence of the maize plant as the host. However, studies on seasonal fluctuations of maize stem borers in maize production systems indicated that stemborers infest maize immediately after crop emergence in all growing seasons (Chabi *et al.*, 2005). Also, though maize is exotic to Africa, but except for *Chilo partellus* all the other stemborer species in Sub Saharan Africa are indigenous species that probably evolved with indigenous grasses (Atkinson, 1980; Schulthess *et al.*, 1997). Yet, these indigenous grasses are found in close association with maize fields and may be serving as alternate hosts ensuring year-round presence of the borers.

1.2. Problem statement

In Uganda, 31% grain yield loss has been associated with stemborer damage (Kalule *et al.*, 1994). During the dry season, the larvae, usually of the third and fourth generation, enter a period of arrested development which usually occurs during adverse environmental conditions especially after crop harvest. This would suggest a reduction in stemborer incidence and infestation in the subsequent cropping seasons. But stemborers infest maize fields immediately at whorl stage whenever the crop is grown. Bowden (1976) theorized that wild grasses are reservoirs for stemborers and thus responsible for several attacks in crop fields. However, Khan *et al.* (1997), Schulthess *et al.* (1997), and Ndemah *et al.* (2002) indicated that wild grasses are more of trap plants than reservoirs for crop pests. Results of subsequent field trials on the subject showed variable results (Ndemah *et al.*, 2006; Kauma *et al.*, 2006). In Uganda in particular, incidence levels of stemborers have been increasing (Kauma, *et al.*, 2006) and it is not clear what is

causing the increasing trend. Studies elsewhere showed that wild grasses around maize fields are reservoirs for stemborers (F.N.Munyeko *et al*, 2003). However, there is limited information on the relationships between wild grasses and occurrence of stemborers and their natural enemies in Uganda. Also, the inter-relationships between stemborers and their natural enemy complex with regard to intercropping system in Uganda are not yet quantified for better exploitation/avoidance in pest management on maize.

1.3 Justification of the study.

Biological control has tremendous potential in the management of stemborers on cereals in general and maize in particular in Uganda (Kauma *et al*, 2006). In order to best utilise existing biological control agents, it is essential to understand the biology and ecology of the pest and the natural enemies in the context of the environment they are embedded in. The factors that are at play are both local and landscape scales. Intercropping has been indicated to promote natural enemies of insect pests for a number of crops (Chabi *et al*, 2005) but can the same be true for maize stemborers in an on-farm setting? Also, are the wild grasses in the vicinity of maize fields in farming communities' hazardous stemborer reservoirs or necessary habitats for natural enemies of the pest? The present research project aimed at finding answers to these key questions and generating recommendations for sustainable managements of the borers on maize in Uganda.

1.4 Main Objective

The major objective of the study was to contribute to development of a sustainable maize production system by establishing the effect of local and landscape ecological factors on stem borer-natural enemy population dynamics.

1.5 Specific Objectives of the study were;

1. To determine the effect of intercropping on occurrence of lepidopteran stemborers and associated natural enemies in maize farming systems
2. To compare the abundance of maize stemborers and their natural enemies on maize and associated grasses in Uganda.

1.6 Hypotheses;

The following hypotheses were tested:

1. Maize cropping systems do not affect the occurrence of lepidopteran stembores and their associated natural enemies
2. The grasses surrounding maize farms sustain higher numbers of lepidopteran stemborers and associated natural enemies than the planted maize.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Nomenclature, description and taxonomy of Maize

The terms maize and corn are used to refer to *Zea mays*. The name *zea* is a Greek word meaning cereal or grain and the specific epithet *mays* is derived from the native Arawak word *maiz* or *mahiz* used by Americans to describe the plant. The word was adopted by the Spanish crew of Columbus's first voyage who first collected the grains from America and took it to Europe (Hyam and Pankhurst, 1995; Desjardins and McCarthy, 2004). Maize is an annual monocotyledonous diploid ($2n=20$) plant belonging to the family *Poaceae* and sub-family *Panicoideae*. It is in the *Maydeae* tribe, sometimes referred to as *Anthropogoneae* of which eight different genera have been recognized by taxonomists. *Tripsacum* which has numerous wild species and *Zea* are considered genera of the new origin (Norman *et al.*, 1995). The genus *Zea* has four species namely *Z. diploperemis*, *Z. peremis*, *Z. luxuria* and *Z. mays*, with *Z. mays* having four sub species which are: *mexicana*, *parviglum*, *huehuetenangenis*, and *mays* (Norman *et al.*, 1995).

2.2 Agronomy and Ecology of Maize

Maize is a versatile crop; growing across a range of agro-ecological zones and thrives best in warm climates and is now grown in most of the countries that have suitable climatic conditions. In the temperate zones, its growth depends more on high summer temperatures than on a high mean temperature. It will ripen in a short hot summer, and will withstand extreme heat (NARO 2005, 2007). A large amount of water is needed during the growth of maize with its average maturity period being relatively short which makes it possible to grow at fairly high latitudes (NARO, 2010). The crop is also suited to cultivation in otherwise poor growing conditions related to topography, soils, climates, and elevation. Significantly, maize does well in exceptionally wet climates unsuited to wheat or relatively arid regions unsuited to rice cultivation (The Food and Culture Encyclopaedia, 2010).

Adapted to a wide range of climates, the crop is mostly grown between latitudes 30°E and 55°N. Due to its wide adaptation, it flowers at different times of the year depending on the cultivar selected during the growing season, some will mature in 90 days after emergence while others require over 120 days. Spacing between rows ranges from 50-100 cm and 30-75 cm between

crops respectively, with a soil pH 6.0-7.2, and ambient temperatures ranging from 21°C to 27°C. It does not grow well when the mean temperature is above 27° C (Balirwa, 1992) or below 19° C. The crop does well on any soil with adequate drainage to allow for the maintenance of sufficient oxygen for good root growth and activity, and enough water-holding capacity to provide adequate moisture throughout the growing season. The production potential of maize is however, not attained or realised due to a number of biotic and abiotic factors. One of the biotic factors that reduce crop yield are insect pests which infest the crops both in the field and in storage.

2.3 Lepidopteran stem boring insect pests complex of maize in Uganda.

The most damaging species of stemborers in Uganda are *Sesamia calamistis* (Lepidoptera: Noctuidae), *Eldana saccharina* (Lepidoptera: Pyralidae), *Busseola fusca* (Lepidoptera: Noctuidae) (Abu, 1986) and *Chilo partellus* (Lepidoptera: Pyralidae) which is of Asian origin but is now widely distributed into Eastern Africa (Bosque Perez, 1995). In Uganda all the four species of stalk borers occur in the maize growing areas (Okoth and Kalule, 1990). The seasonal stemborer populations in Uganda were estimated to be 45% *C. partellus*, 25% *B. fusca*, 19% *E. saccharina* and 11% *S. calamistis*, with *C. partellus* and *B. fusca* starting infestation early in the season. Significant reduction in yield due to stemborers has been reported in all the major producing areas in Uganda (Bowden, 1956, 1976; Girling, 1980, Kauma *et al.*, 2003).

2.3.1 Distribution, ecology, biology, and damage by *Busseola fusca* (the African maize stemborer)

Busseola fusca is distributed widely throughout sub-Saharan Africa. In the eastern and southern Africa, *B. fusca* is restricted to mid-and high elevations areas (>600m.a.s.l), whereas in West Africa, the same species is found at all elevations, but is most abundant in the savannah zone (Overholt *et al.*, 2001). The pest has been recorded in Angola, Benin, Botswana, Bukina faso, Cameroon, Ethiopia, Ghana, Guinea, Cote d'Ivoire, Kenya, Lesotho, Malawi, Mali, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Swaziland, Tanzania, Uganda, Zaire, Zambia and Zimbabwe (Harris and Nwanze, 1992). The pest thrives on wide number of other cultivated and wild host plants; mostly of the grass family (Khan *et al.*, 1997). The female *B. fusca* lays eggs in batches of 30-50, inserted between the leaf sheath and the stem. Incubation lasts about 1 week. After hatching, the larva feeds on the young blades of the leaf whorl and then, suspended from silk strands, spread to neighbouring plants. They penetrate the

stems by boring through the whorl base, destroy the growing points and tunnel downward. After passing through six to eight instars stages (30-45 days), they chew an outlet for the adult and pupate in the tunnel. Pupation lasts 10-20 days. Up to four generations are produced per year. At the end of the rainy season, the larvae of the last generation enter diapause in maize and sorghum stubble or in wild grasses. They pupate a few months later, just before the start of the following rainy season.

In Sub-Saharan African countries, *B. fusca* is considered the most important pest of maize, with yield loss as high as 40% attributed to its infestations (Kauma, 2005). In DRC for instance, *B. fusca* occasionally caused yield losses of 8-9% in early-planted maize, and 22-25% in late-planted maize. In Cameroon, Cardwell *et al.* (1997) reported grain loss at 4.6g per borer in lowland fields and 8.7g per borer in highland fields. The following plants were recorded as hosts of *B. fusca*: *Zea mays*, *Sorghum vesicolar*, *Saccharum officinarum*, *Hyparrhenia rufa*, *Panicum maximum*, *Pennisetum purpureum*, *Rottboellia compressa*, *Sorghum verticilliflorum* (Bleszynski, 1970), *Echinochloa haploclada*, *Echinochloa pyramidalis*, *Panicum deustum*, *Rottboellia cochinchinesis*, *Setaria incrassate*, *Sorghum arundinaceum*, *Sorghum vesicolor*, *Sorghum vulgare* var. *sudanense*, *Sporobolus marginatus* (Khan *et al.*, 1997). But information on alternate hosts of *B. fusca* especially wild grasses in Uganda is scanty hence this study.

2.3.2 Distribution, ecology, biology, and damage caused by *Sesamia calamistis* (the Pink stemborer)

Sesamia calamistis occurs in most of tropical Africa. Country records include South Africa, Zimbabwe, Malawi, Uganda, Tanzania, Kenya, Zanzibar, Madagascar, Mauritius, Reunion, Angola, Nigeria, Cote d'Ivoire, Cameroon, Gambia, Ghana, (Tams and Bowden, 1953), Mozambique (Cugala *et al.*, 1999), Ethiopia (Gebre-Amlak, 1985). In 3-5 days, the female lays up to 350 eggs, deposited in batches of 10-40. The eggs are arranged in two to four contiguous rows and inserted between the lower leaf sheaths and stem. Several hours after hatching, the larvae leave the oviposition site to penetrate the stems either directly or after feeding on the leaf sheath. During the larval stage, which lasts 30-60 days, depending on the climatic conditions, and usually involves five to six moults, larvae may successively attack a number of young stems or tillers. Pupation takes place in the stem, rarely between the sheath and stem. The pupal period lasts 10-12 days at 25°C. Under tropical conditions five to six generations are completed in a

year. *Sesamia calamistis* breeds throughout the year without diapause even under severe dry weather and have no distinct periods of emergence of adults as in the case of *B. fusca* (Bosque-Perez and Schulthess, 1998). The hosts of *S. calamistis* include; Maize, sorghum, finger millet, rice, sugarcane (Nye, 1960), *Andropogon* sp., *Cenchrus ciliaris*, *Coix lacryma-jobi*, *Echinochloa haploclada*, *Echinochloa*, *Echinochloa pyramidalis*, *Hyparrhenia filipendula*, *Hyparrhenia rufa*, *Panicum maximum*, *Pennisetum purpureum*, *Phragmites* sp., *Setaria sphacelata*, *Sorghum arundinaceum*, *Sorghum vulgare* var. *Sudanense*, *Tripsacum laxum*, *Vossia* spp., *Cyperus distans*, *Cyperus immensis*, *Cyperus papyrus*, *Typha domingensis* (Khan et al., 1997). Therefore this study was instituted to establish the wild host diversity of this pest in Uganda.

2.3.3 Distribution, ecology, biology, and damage caused by *Eldana saccharina* (the African sugar cane borer)

Eldana saccharina is widely distributed in sub-Saharan Africa including Uganda, Burundi, Chad, Ghana, Kenya, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Tanzania, and Zaire (Maes, 1998). Girling (1978) published a detailed account of the biology, distribution and natural hosts of the species in Uganda, while Atkinson (1980) did the same in Natal, South Africa, and Sampson and Kumar (1985) studied this species in Ghana. Females lay batches of 50-100 eggs on dry leaves at the base of the plants, which may partly explain the tendency of *E. saccharina* to infest mature crops. Eggs hatch after about 6 days and the young larvae feed externally on epidermal tissue before penetrating the stems. The length of larval development is variable and may take up to 2 months. Larvae pupate within the stems. Up to six generations may occur in a year and there is no larval diapause. In East and Southern Africa, *E. saccharina* is considered to be a serious pest of sugarcane (Atkinson, 1980). In East Africa, *E. saccharina* attacks maize, but usually towards the end of the growing season, and is generally considered a serious pest. The following plants were recorded as host of *E. saccharina*: Sugarcane, maize, rice, sorghum, *Panicum maximum*, *Pennisetum purpureum*, *Phragmites* sp., *Rottboellia cochinchinensis*, *Sorghum arundinaceum*, *Sorghum vesicolor*, and *Sorghum vulgare* var. *sudanense*, *Cyperus distans*, *Cyperus immensis*, *Cyperus maculatus* and *papyrus* (Khan et al., 1997). In Uganda its major host is *Saccharum officinarum* with less preference for maize, therefore this study was conducted to establish the alternate host especially wild hosts for this pest.

2.3.4 Distribution, ecology, biology, and damage caused by *Chilo partellus* (the spotted stalk borer)

Chilo partellus is native to Asia where it is considered to be a pest of maize and sorghum. It was reported in Africa in 1930 in Malawi, and has since spread to most countries in Eastern and Southern Africa, including Ethiopia, Kenya, Malawi, Mozambique, Somalia, South Africa, Sudan, Tanzania, Uganda (CAB, 1977), Botswana, Swaziland, Zimbabwe (Sithole, 1990), Comoro Islands, Madagascar (Bleszynski, 1970; Delobel, 1975). Additionally, recent findings by ICIPE have found *C. partellus* in Eritrea, Zambia, Zanzibar and Somalia (ICIPE, unpublished). Adults emerge from the pupae in the late afternoon and early evening and are active at night. During the day they rest on plant debris. Females mate soon after emergence and oviposit for two to three subsequent nights, in batches of 10-80 overlapping eggs, on the upper and undersides of leaves, mainly near the midribs and at times on the stem. Adults live for about 2-5 days and do not normally disperse far from emergence sites. Eggs hatch in 4-5 days after being laid and young larvae ascend plants to enter the leaf whorls, where they start to feed. Older larvae tunnel into stem tissue, and after feeding for 2-3 weeks, pupate in the stem for 5-12 days. Under favourable conditions, the life cycle is completed in 25-50 days, and five or more successive generations may develop during a single maize growing season. In cold and/or dry conditions, larvae may enter a resting stage (diapause) in stems, stubble and other crop residues, where they spend up to 6 months before pupating when favourable conditions occur in the next growing season. The following plants are recorded as hosts of *C. partellus*: Maize, sorghum, rice, sugarcane, *Eleusine coracana*, *Hyparrhenia rufa*, *Panicum maximum*, *Pennisetum purpureum*, *Rottboellia compressa*, *Sorghum verticilliflorum*, *Vossia cuspidate* (Bleszynski, 1970), *Cenchrus ciliaris*, *Coix lacryma-jobi*, *Dactyloctenium aegyptium*, *Echinochloa haploclada*, *Echinochloa pyramidalis*, *Hyparrhenia filipendula*, *Hyparrhenia pilgerana*, *Hyparrhenia rufa*, *Panicum deustum*, *Panicum maximum*, *Pennisetum purpureum*, *Pennisetum trachyphyllum*, *Phragmites* sp., *Rottboellia cochinchinesis*, *Setaria incrassata*, *Sorghum arundinaceum*, *Sorghum vesicolor*, *Sorghum vulgare* var. *sudanense*, *Sporobolus marginatus* (Khan et al., 1997). Part of the stem borer population may remain active in wild grasses during the season (Overholt et al., 2001). *Chilo partellus* is now considered to be the most important stem borer in most low to medium elevation areas of Eastern and Southern Africa. Yield losses in maize of about 18% were attributed to *C. partellus* and *C. orichalcociliellus* in the southern coastal area of Kenya

(Warui and Kuria, 1983), and 50% in southern Mozambique (Sithole, 1990). Losses of 2-88% due to *C. partellus* have been reported in sorghum in Kenya (Seshu-Reddy, 1998) and 12-31% loss maize yield loss in Uganda (Kalule *et al.*, 1998).

2.4 Natural enemies of stemborers on maize

Most of the research attempts to solve pest problems in Sub Saharan Africa have focused on an integrated approach, including host plant resistance (Bosque-Perez *et al.*, 1997), biological control (Schulthess *et al.*, 1997, 2001; Ndemah *et al.*, 2001 a, b) and habitat management technologies based on management of soil nutrients (S'etamou *et al.*, 1993, 1995; Denk'e *et al.*, 2001), trap plants (Ndemah *et al.*, 2001) and mixed cropping systems (Schulthess and Ajala, 1999; Ndemah *et al.*, 2003; Schulthess *et al.*, 2004). Biological control of lepidopterous stem borers has been considered a major component of integrated pest management (IPM) strategies in Africa (Schulthess *et al.*, 1997; S'etamou *et al.*, 1999). Stem borer biological control complex include; predators, parasitoids, nematodes, and pathogens (Kfir *et al.*, 2002). Mohyuddin and Greathead (1970) inventoried insect parasitoids and predators of stem borers in East Africa. Several workers (Mohyuddin, 1990; Bonhof *et al.*, 1997) reviewed the biological control agents of stem borers from egg to pupal stage. Diverse groups of both indigenous and exotic parasitoids attack stemborers in Sub-Saharan Africa (Bonhof *et al.*, 1997; Overholt 1998; Zhou *et al.*, 2003; Mailafiya *et al.*, 2009). Most of the stemborer egg parasitoids are Hymenoptera belonging to the genera Trichogramma, Trichogrammatoidea, and Telenomus (Mohyuddin, 1990; Bonhof *et al.*, 1997). The most common larval parasitoid for cereal stemborers in many Sub-Saharan countries is *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) and its parasitism ranges between 0-20% (Kalule and Ebellu, 1997; Overholt *et al.*, 1997). Another common native parasitoid is *Sturmiopsis parasitica* Curran (Diptera: Tachinidae) found in eastern and southern Africa (Bonhof *et al.*, 1997). It is primarily common in drier areas of Africa as reported in parts of Tanzania (Mohyuddin and Greathead, 1997). Another effective larval parasitoids is the recently introduced *Cotesia flavipes* in Eastern Africa whose high reproductive potential and searching ability made it a better competitor and is slowly replacing the native parasitoid *Cotesia sesamiae* Cameron (Kauma, 2005)

Of the pupal parasitoids, the most commonly encountered are Hymenopterans; *Dentichasmias busseolae* Heinrich (Ichneuemonidae), *Pediobius furvus* Gahan (Eulophidae) and *Psilochalcis*

sudanensis (Chalcididae) (Bonholf *et al.*, 1997). Mathez (1972) observed that *D. busseolae* could cause up to 56% mortality in pupal populations of *Chilo partellus* in East Africa.

2.5 Factors influencing Distribution and Efficacy of Parasitoids

A major factor affecting the efficacy of parasitoids is the suitability of the stemborer species and the host plants they feed on (Hailemichael *et al.*, 2008). *Cotesia* species belong to a group of parasitoids known as koinobionts. These parasitoids allow their parasitized host larvae to continue feeding while the parasitoid immatures develop within the host. Hailemichael *et al.* (2008) (for *C. sesamiae*) and Jiang *et al.* (2004) (for *C. flavipes*) showed that depending on the *Cotesia* species, parasitized stemborer larvae feed and continue growing at the same rate as unparasitized ones. In addition, their growth rate is greatly influenced by temperature and host age (Jiang *et al.*, 2004). Such intimate parasitoid-host relationships expose young parasitoid life stages to the host's immune system (Godfray, 1994; Pennachio & Strand, 2006), in addition to allelochemicals in the host diet (Barbosa *et al.*, 1986, 1990; Cortesero *et al.*, 2000; Sznajder & Harvey, 2003; Ode, 2006). However, due to their inability to metabolize plant secondary compounds present in their hosts (Quicke, 1997); the parasitoids are more susceptible to these compounds as compared to their phytophagous hosts. For example, for *C. flavipes*, survival was shown to be lower and immature developmental time longer when *C. partellus* was feeding on wild instead of cultivated plant species (Sétamou *et al.*, 2005). During foraging, parasitoids use volatile chemical cues (info chemicals), to guide them to a specific host habitat and to eventually locate the host (Vinson, 1975). Successful parasitism of hosts is preceded by a sequence of events which include: host habitat location, host location, host acceptance and host suitability (Vinson, 1976). The ability to perceive info-chemicals is an important factor in host location, selection, evaluation, actual handling and eventual parasitism (Dicke & Vet, 1999). For example, in olfactometric studies *C. flavipes* females preferred odours from stemborer-infested plants over those from their uninfested counterparts (Potting *et al.*, 1993; Ngi-Song *et al.*, 1996; Jemberé *et al.*, 2003; Obonyo *et al.*, 2008). Studies by Potting *et al.* (1993) and Ngi-Song *et al.* (1996) revealed that *C. flavipes* and *C. sesamiae* were remotely attracted to stemborer-infested plants regardless of the species (herbivore or host plant) used. Furthermore, the wasps could not discriminate between host plants infested by *C. partellus*, *C. orichalcociliellus*, *B. fusca* or *S. calamistis*. This implies that the parasitoids cannot remotely detect the suitability of stemborer

species in the plants. Therefore, the volatiles do not carry any information on the damaging herbivore species (Ngi-Song & Overholt, 1997). It appears that discrimination of hosts occurs at “short-range” rather than “long-range”, i.e., once the parasitoid has made contact with the herbivore larvae.

For biological control to be a reliable and effective method, insight is needed into the foraging behaviour of candidate natural enemies. Host location and attack is a key determinant of the efficiency of a given parasitoid population; thus, variability in host-location or host-selection can be a major source of inconsistent results in biological control with parasitoids (Godfray, 1994). Another key factor for parasitoid distribution is the introduction of biological control agents against stemborers in Africa. This has been ongoing for the past 50 years. *Cotesia sesamiae* indigenous to east Africa was introduced to Mauritius, Reunion and Madagascar against *Sesamia calamistis* and it successfully established (Overholt, 1998). Similarly *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) an exotic parasitoid of *Chilo partellus* is now established in a number of African countries with variable success. In maize, stemborers pupate close to the tunnel exit or even partly outside the stem (Smith *et al.* 1993), which increases their accessibility to parasitoids (Ndemah *et al.* 2001). On the contrary, in wild host plants, stemborers seldom pupate within plant stems, but rather on the outside often at the bottom of plants close to the roots in the soil (Mailafiya 2009).

2.5.1. Parasitoid host location and recognition

Despite their cryptic lifestyle, stemborers do not escape parasitism by their natural enemies. This is because parasitoids have evolved various strategies of attacking concealed hosts living inside plant stems. Smith *et al.* (1993) grouped the strategies employed by parasitoids to attack stemborer larvae into four categories: (i) “probe and sting” tactic, where parasitoids probe through the leaf sheath to find early instar larvae; while other species probe through the exit hole of the stem tunnel to find mature larvae and sting them. (ii) “wait and sting”, where parasitoids insert their long ovipositors through one of the tunnel holes then wait till the host larva passes by and is close enough for oviposition to occur. (iii) The “drill and sting” strategy parasitoids have long and strong ovipositors to attach to their hosts at a distance from outside the stalk. Parasitoid species such as *Cotesia* spp. which have small ovipositors adopt (IV) the “ingress and sting” tactic, since they are small enough they enter the stem tunnel and parasitise their hosts.

Host location is the process whereby parasitoids perceive and orient towards their hosts from a distance by responding to stimuli originating from the host or its products (Smith *et al.*, 1993). During host location, parasitoids utilize both long and short-range chemical stimuli (info chemicals) arising from the host habitat or from the host itself (Godfray, 1994). Vinson (1976) categorized the process resulting in successful host parasitism by insect parasitoids into four steps: (i) host habitat location (ii) host location (iii) host acceptance, and (iv) host suitability. The first three steps constitute the host selection process. Habitat and host location constitute long-range approaching behaviour based upon reception of volatile compounds. In each of these, female parasitoids often use chemical stimuli to guide them in searching for suitable hosts. Perception of info chemicals is an important component in host location, selection, evaluation, actual handling and eventual parasitism (Dicke & Vet, 1999). The sources of these info chemicals are also broadly categorized into three: (i) stimuli arising from the host microhabitat or food plant (ii) stimuli indirectly associated with the presence of the host, and (iii) stimuli arising from the host itself (Vinson, 1976). Although these categories blend into each other, their ranking roughly reflects their increasing importance as indicators of host presence (Godfray, 1994). Chemical stimuli emanating from the hosts and their habitat are directly involved in communication and exert influence on other trophic levels. These tritrophic interactions involving plants, herbivores and their natural enemies represent an intricate array of chemical substances known as allelochemicals (Vinson, 1976). Long-range attractants arise from the host communication system and host food (Vinson, 1976). These volatile allelochemicals are the most reliable cues for the foraging parasitoid only if they are specific for the herbivore species or when the cues can be learned by a searching parasitoid (Dicke & Vet, 1999). Damaged plant tissue plays a major role in narrowing the search area for natural enemies once located in the host community. Once near a potential host community, foraging parasitoids often fly over damaged plants landing briefly while antennating for useful cues, if the cues produced are not useful, the parasitoids immediately resume their search (Vinson, 1975). For example, the braconid parasitoid *Cardiochiles nigriceps* Viereck once situated in a tobacco field flies 2-3 cm above the plant, lands briefly and antennates damaged plant tissue. Should the damage be mechanical or not due to an insect, the parasitoid resumes her search. However, if the damage is due to a potential host, the behaviour of the parasitoid changes from flying to crawling on the plant (Vinson, 1975). The importance of plant cues in *C. flavipes* and *C. sesamiae* orientation toward

various hosts has been observed from behavioural studies in the laboratory using olfactometric bioassays. For example, the female parasitoids prefer odours from stemborer-infested plants over those from their uninfested counterparts (Potting *et al.*, 1993; Ngi-Song *et al.*, 1996; Jembere *et al.*, 2003; Obonyo, 2005; Obonyo *et al.*, 2008). Allelochemicals emitted by infested plants which are attractive to *C. flavipes* and *C. sesamiae* primarily consist of green leaf volatiles such as (E)-4,8-dimethyl-1,3,7-nonatriene and (Z)-hexenyl acetate and alcohols such as phenol (Ngi-Song *et al.*, 2000; Obonyo, 2005; Obonyo *et al.*, 2008). Plants accumulate compounds as “chemical reserves” in specialized glands and upon infestation their leaves produce green leaf volatiles (GLVs) by breaking down membrane lipids (blends of saturated and non-saturated C₆-alcohols, aldehydes and esters) (Paré & Tumlinson, 1999).

2.6 Biology and ecology of key parasitoids of the stem borers

2.6.1 *Cotesia* species

The *Cotesia* “complex” comprises of three species (syn.*Apanteles*) namely, *C. flavipes*, *C. sesamiae* and *C. chilonis* (Overholt, 1993; Walker, 1994). These are hymenopterans in the family Braconidae and subfamily Microgasterinae. They are gregarious endoparasitoids of medium sized pyralid and noctuid stemborers. *Cotesia flavipes* is endemic to Asia and Australia, *C. sesamiae* is native to Africa and *C. chilonis* occurs in Japan. *Cotesia sesamiae* is believed to have evolved together with wild grasses in east Africa (Mohyuddin and Greathead, 1970). Of the three *Cotesia* species *C. sesamiae* is native in Uganda and *C. flavipes* is an introduced species that has proved effective in the management of *C. partellus*, which is also an invasive stemborer species in Uganda. All these three species are similar in their biology and morphology (Overholt, 1993) and can only be distinguished basing on the morphology of the male genitalia (Kimani and Overholt, 1997). They attack mid to late instar stem borer larvae. Adults start mating immediately after emergence (sib-mating) especially in bright light. Males emerge first and wait near the cocoons for the female to emerge (Ulllyte, 1935). A female’s clutch size is 40-60 eggs (Potting *et al.*, 1999; Mochiah *et al.*, 2001). The fully developed larvae emerge from the host larva and spin white cocoons which are loosely held together with fine silky strands. The average egg to adult development time is 18 days at 25°C (Ngi-Song *et al.*, 1995; Mochiah *et al.*, 2001). Longevity of the adult wasp is between 2-10 days depending on the availability and type of food (Sathe *et al.*, 2001). *Cotesia* species are attracted to its host by volatiles emanating from graminaceous host plants. Herbivore damage increases the attractiveness of the host plants to the wasp (Ngi-Song *et*

al., 1996; Rutledge and Weidemann, 1999). Frass also plays a role in short term host location by the wasps (Ngi-Song and Overholt, 1997; Potting *et al.*, 1999).

In Uganda the most commonly occurring *Cotesia* species are *C. sesamiae* which is believed to have evolved together with the native stemborers especially *B. fusca* (Kauma *et al* 2000). During oviposition, most parasitic Hymenoptera co-inject with their eggs factors that are responsible for suppression of the host's immune response, including venom from their accessory glands (Asgari *et al.*, 2003) as well as polydnviruses that work in synergy to bring about host regulation and immune suppression (Richards & Parkinson, 2000). The presence of the virus is asymptomatic in the wasp but causes major physiological disturbances in host larvae in which several viral genes are expressed. The most commonly observed pathologies in infected caterpillars are suppressed immunity and developmental arrest prior to metamorphosis. These two conditions are essential for the survival and growth of the wasp larvae inside its hosts (Beckage & Gelman, 2004). Recent findings on the interaction of *C. flavipes* with native, non-target lepidopteran stemborer species in Africa showed that this exotic parasitoid has a high specificity for its aboriginal host *C. partellus* (Obonyo, 2005) and with minimal non-target harm (Obonyo *et al.*, 2008). In addition, *C. flavipes* has a higher searching efficiency attacking more larvae than *C. sesamiae* when *C. partellus* is the host. This shows that it is a more efficient parasitoid against *C. partellus* than the indigenous *C. sesamiae* (Sallam *et al.*, 1999). With the exception of *B. fusca* in which *C. flavipes* eggs are encapsulated, the parasitoid attacks and successfully develops in several other stemborer species such as *C. partellus*, *C. orichalcociliellus* and *S. calamistis* (Ngi-Song *et al.*, 1995).

2.6.2 *Dentichasmias busseolae* Heinrich (Hymenoptera; Ichneumonidae)

Dentichasmias busseolae is a solitary pupal endo parasitoid of stemborers. Adults are about 7-11.5 mm long. In females, the ovipositor slightly protrudes beyond the gaster, a characteristic used to distinguish females from males. The species derives its name from two small teeth found on the apical margin of the clypeus (Zwart, 1998). Though it has been found on several stem borers, *Dentichasmias busseolae* is mainly a parasitoid of *Chilo partellus* (Mohyuddin, 1972; Oloo and Ogeda, 1990; Kfir, 1992). This is counter intuitive as the parasitoid is African and *Chilo partellus* is from Asia. *Dentichasmias busseola* may have been a parasitoid of African *Chilo* species which quickly adapted to the exotic species (Zhou *et al*, 2003). The life cycle of *Dentichasmias busseolae* has been described by Mohyuddin (1972) and Bahana (1989). Mating

occurs immediately after emergence of the female and lasts for about 3 minutes. The mating behaviour of the male is controlled by a pheromone produced by the female just before emergence (Bahan 1989). On perceiving the pheromone, males vibrate their wings and attempt to mount the pupae even before the female adult emerge (Bahan, 1989). Newly emerged females are more attractive to the males than the old ones. A single egg is laid in a 1-2 day old pupa, which develops through five instars before pupation. The adult emerges from the host pupae 16-18 days at 25°C, adult females live on average 36-40 days during which period they lay about 80 eggs (Bahan, 1989).

2.6.3 *Trichogramma* spp

Trichogramma sp is a well-known egg parasitoid widely used as an insect biological control agent worldwide (Stinner, 1977). The genus *Trichogramma* includes more than 100 species throughout the world (van Lenteren, 2000). They are present in agro ecosystems where they attack eggs of Lepidopterans. The lifespan of *Trichogramma* is very short (Newton & Odendael, 1990) typically less than 7 days when no food source is available (Glenn & Hoffmann, 1997; Gurr & Nicol, 2000). The length of time *Trichogramma* is active is directly determined by its longevity (Mansfield & Mills, 2002). *Trichogramma* species have a short generation time and can be easily mass produced and they could kill the Lepidopteran pests during the egg stage before caterpillars can emerge and damage the crop (King *et al.* 1986; Hassan 1993). *Trichogramma* are solitary endoparasitoids, they seek out and parasitize host eggs, more than one egg may be inserted into each host egg and this is based, at least in part, on the egg size. After hatching, the parasitoid larvae feed on the contents of the host egg. The wasps pupate within the egg and adults chew an emergence hole to escape. At a constant 27°C, it takes about 10 days from the time of parasitism to emergence of wasps (Hoffmann *et al.* 1995)

2.6.4 *Sturmiopsis parasitica* Curran (Diptera: Tachinidae)

Another common native parasitoid is *Sturmiopsis parasitica* Curran (Diptera: Tachinidae) found in East and Southern Africa (Bonholf *et al.* 1997). It is primarily common in the drier areas of Africa, as reported from Zimbabwe and parts of Tanzania (Mohyuddin and Greathead, 1970; Greathead, 1990). Although Greathead (1990) suggested the redistribution of *S. parasitica* in African countries, not much research has been carried out to understanding its bio-ecology.

2.7 Influence of crop host diversity on occurrence of stem borers and natural enemies on maize

Traditional farming systems in Africa have been based on intercropping or mixed cropping forms of habitat management as opposed to monocropping systems (Nwanze, 1997; Abate *et al.*, 2001). Intercropping with non-host plants has been found to reduce stem and cob borer densities (Dissemond and Hindorf, 1990). Many studies in tropical as well as temperate zones reported low pest densities in diversified systems (Altieri & Letourneau, 1982; Risch *et al.*, 1983; Andow, 1991; Thies & Tscharnkte, 1999; Kruess & Tscharnkte, 2000). In Africa, such techniques include pest diversion or trap cropping (Khan *et al.*, 1997; Ndemah *et al.*, 2002) and mixed cropping (Litsinger & Moody, 1976; Okigbo & Greenland, 1976; Baliddawa, 1985; Schulthess *et al.*, 2004). There are a number of studies in East Africa that have shown a reduction in stem borer densities when maize was intercropped with non-hosts such as cassava or legumes. Although most of them dealt with the invasive crambid stemborer *Chilo partellus* (Swinhoe) (see overview by van den Berg *et al.*, 1998). Recent work in western Africa showed that maize intercropped with cassava or grain legumes considerably reduced the amount of eggs of the noctuids *Sesamia calamistis* Hampson (Schulthess *et al.*, 2004) and *B. fusca* (Chabi-Olaye *et al.*, 2005), as a result of reduced host finding by the ovipositing adult moths. These results support the disruptive crop hypothesis of Root (1973) and Vandermeer (1989). Omolo and Seshu Reddy (1985) however observed that the results of intercropping might vary depending on the crop combination, location, season and cropping pattern. Many workers have shown insignificant reduction in stemborer infestation when cereals were intercropped with either cowpea or soya bean (Natarajan *et al.*, 1990). For instance intercropping maize and sorghum caused considerable increase of *Chilo partellus* incidence with increased dead hearts (Ogwaro, 1983). Therefore the right kinds of crop combinations have to be selected for a successful control of the borers. Part of this study therefore was to verify whether intercropping systems in maize production could reduce stemborer infestations as an integrated pest management strategy in Uganda basing on the contrasting reports, especially in Africa.

2.8 Influence of wild grasses on occurrence of stem borers and their natural enemies

Grasses comprise a diversity of plants that are among the most important to mankind. A few of the grass species have been selected on the basis of high forage productivity and are cultivated for livestock feed (Boonman 1992), while the majority of the species remain in the wild.

However, increases in human population in the recent past, have led to the clearing of the uncultivated ecosystems both in the semi-arid and humid regions for intensive and continuous cultivation of crops. This threatens grass biodiversity through loss or even extinction of some of the important grasses. Additionally, arthropods, particularly some insects and mites, are major pests of gramineous crops and pasture plants: others, however, are major predators and parasites of these pests, and naturally control their populations (Mohyuddin & Greathead, 1970, Dwumfour, 1990). These natural enemies increase stability both in wild- and agro-ecosystems by responding to herbivorous arthropod upsurges and thus preventing outbreaks. Moreover, other arthropods have additional beneficial roles as pollinators of agricultural crops and wild plants, as links in food webs, and as contributors to soil quality and fertility. Although some arthropod species are shared by both cultivated and wild gramineous plants, many others are specifically associated with only grass species. Therefore, loss of such wild grasses either by extinction or local extirpation around ecosystems will result into loss of their associated arthropod fauna, with potential deleterious repercussions to both wild and cultivated ecosystems. Wild grasses on uncultivated land bordering crops can provide extremely important refugia for insect natural enemies as well as harbouring alternate hosts or prey, therefore enhancing abundance of natural enemies which keep pest populations low. The worsening of most pest problems is linked to the expansion of crop monocultures at the expense of natural vegetation. Several studies have indicated that wild grasses surrounding cereal cropping systems have higher parasitism of stem borers than the cultivated ecosystems and this is attributed to: (1) non-periodic re-colonization of natural habitats by parasitoids (Conlong 1994), and (2) slow stemborer larval growth rates which increases their temporal window of susceptibility to stage-specific parasitoids (Bowden 1976; Overholt 1998). Parasitization of cereal stemborer pests during the non-cropping (off) season may therefore occur mainly in natural habitats (Schulthess *et al.* 1997). Also stemborer parasitism is positively correlated with parasitoid abundance and richness (Mailafiya *et al.* 2010) and parasitism varies with habitat type depending on the prevailing conditions in a given ecosystem (Landis *et al.* 2000; Altieri and Nicholls 2004). Hence, it is imperative to understand the ecological role of natural habitats as a component of the cereal cropping system.

In Kenya, 66 host plant (Le Ru *et al.* 2006a, b; Mailafiya *et al.* 2009) species have been recorded with napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare sudanense*) in the suppression of stem borers in maize and sorghum (Khan *et al.*, 1997a, Khan *et al.*, 2001; Van

den Berg *et al.* 2001). Munyeko *et al.* (2003), recorded 23 wild grasses as alternative hosts for stemborers in Kenya. There is also evidence elsewhere in the world to show that molasses grass (*Melinis minutiflora*) when intercropped with maize has been demonstrated to not only repel stemborers but also increases stemborer parasitism by a natural enemy, *Cotesia sesamiae* (Khan *et al.* 1997). In Uganda, intercropping with non-host plants in regards to agronomic crop management has been documented; yield loss associated with stemborers have also been documented (Kauma, 2000; Hussein *et al.*, 1997,), but little work has been carried out to establish the level of infestation of the prevailing alternative wild hosts for the stemborers and hence their potential role in the management of these borers by their natural enemies. Therefore, this study aimed to bridge this gap as well as establish the effect of intercropping maize at the local scale.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Study sites

The study was conducted in 2012 and 2013 in western Uganda, Kiryandongo district which lies at 1° 22' N 31° 22'E with a mean elevation of 1,158m above sea level and the district is well known for commercial maize production. Kiryandongo district is characterized by bimodal distribution of rain fall, with peaks in April and September and an annual precipitation of about 1500mm. The short and long rainy seasons last from mid-March to end of June and from early August to end of November, respectively. A short dry spell of about four weeks occurs in July. The major dry spell begins in the last week of November and lasts until mid-March with an annual average temperature of 25°C. Since the predominance of Lepidopteran stem borer species varies with season (Schulthess *et al.*, 1997), surveys were conducted for two cropping seasons in Kiryandongo district; Bweyale and Diika sub counties while supporting laboratory specimen identification was carried out at the Crop Science laboratory at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK). Bweyale and Diika parishes were selected basing on information provided by Kiryandongo District Agricultural Office which indicated that the two sub counties were among the main maize growing areas of the district and Uganda at large with organized farmer groups.

3.2 Selection of the study Area

This was an ecological study which required careful assessment and selection of the study site (District) basing on two factors; Cropping system (Monocropping systems or Intercropping systems and proximity to a grassland with wild grass species within a radius of 500m of the maize field. In order to achieve this a preliminary survey was carried out in the major maize growing districts of Uganda and a comparative study of wild grass species richness surrounding maize fields was carried out in 2012 as described below.

Five random quadrats each measuring 1m x 1m were established within each study area. All grass species in the quadrat were identified and recorded. The random quadrat sampling method (Githae *et al* 2007) was used to collect data on densities, frequency, foliage cover (%), and cover of grass within each quadrat. For every grass encountered calculations of: (i) relative frequency (RF), which is the number of plots in which a species occurred divided by the total number of

occurrences of all species in plots; (ii) Relative cover (RC) which is the percent total cover of all grasses of a single species within each quadrat, (iii) relative dominance (RD), which is the basal area of a species divided by the sum of basal areas of all species were done as per the guidelines of Githae *et al* (2007). The importance value index (IVI) was then calculated by the summation of RC + RF + RD. Species diversity was calculated using the Simpson's Diversity index $= \lambda = \sum (n_i/N)^2$ as shown in the table 1 & 2 below.

3.3 Species composition of grasses in vicinity of the maize fields

The grasses in table 1 were the most dominant grass species in the study area. Density of the grasses differed significantly based on their relative cover and dominances (Table 1 & 2). The highly dominant grass species were *P. purpureum* with a relative dominance of 14.5, *P. polystachion* at 10.6, *H. rufa* 9.6, *P. maximum* 9.5, and *S. vesicular* 8.6. The Simpson's diversity index for the grasses ranged from 0.87- 0.9 (Tables 1 & 2).

Table 1: Composition and occurrence of grasses in the vicinity of intercropped maize fields

Species names	Field 1	Field 3	Field 4	Field 5	Field 6	Field 8	Field 9	C	RC	D	RD	F	RF
<i>Panicum maximum</i>	77	68	45	9	63	12	41	2.03	0.09	3.15	9.47	100	9.9
<i>Pennisetum purpureum</i>	56	89	56	148	14	49	71	1.34	0.09	4.83	14.52	100	9.8
<i>Sorghum vesicolor</i>	68	41	62	10	32	35	39	0.45	0.09	2.87	8.63	100	9.87
<i>Eleusine coronaca</i>	18	32	102	0	42	11	23	0.56	0.08	2.28	6.86	85.6	8.45
<i>Heteropogon contortus</i>	127	44	11	2	9	6	33	0.09	0.09	2.32	6.98	100	9.86
<i>Cynodon dactylon</i>	68	50	63	14	54	57	0	0.21	0.08	3.06	9.20	85.6	8.45
<i>Saccharum officinarum</i>	20	50	48	56	27	0	96	0.22	0.08	2.97	8.93	85.6	8.45
<i>Hyperthemia rufa</i>	145	88	62	20	0	6	0	0.88	0.07	3.21	9.65	71.43	7.044
<i>Pennisetum polystachion</i>	83	5	66	130	67	0	4	0.48	0.08	3.55	10.67	85.6	8.45
<i>Cyperus scariosus</i>	8	151	28	12	42	10	2	0.01	0.09	2.53	7.61	100	9.86
Totals									0.84		92.5		100

Note: Important value index = $RD+RC+RF$ where RD: Relative Density; RC: Relative Cover; RF: Relative Frequency. = $92.5+84+100=276.5$ or 2.76%; Simpson's Diversity Index: (Use inverse Simpson's Index)

D: $1 - \lambda$ Where $\lambda = \sum (ni/N)^2$

Where,

D = Diversity

N = total number of individuals

n = numbers of each different species (relative abundance of each species)

D: $1 - \lambda$ Where $\lambda = \sum (ni/N)^2 = 0.9$

H'=0.9

Table 1: Composition and occurrence of grasses in the vicinity of intercropped maize fields

Species names	Field 1	Field 3	Field 4	Field 5	Field 6	Field 8	Field 9	C	RC	D	RD	F	RF
<i>Panicum maximum</i>	77	68	45	9	63	12	41	2.03	0.09	3.15	9.47	100	9.9
<i>Pennisetum purpureum</i>	56	89	56	148	14	49	71	1.34	0.09	4.83	14.52	100	9.8
<i>Sorghum vesicolor</i>	68	41	62	10	32	35	39	0.45	0.09	2.87	8.63	100	9.87
<i>Eleusine coronaca</i>	18	32	102	0	42	11	23	0.56	0.08	2.28	6.86	85.6	8.45
<i>Heteropogon contortus</i>	127	44	11	2	9	6	33	0.09	0.09	2.32	6.98	100	9.86
<i>Cynodon dactylon</i>	68	50	63	14	54	57	0	0.21	0.08	3.06	9.20	85.6	8.45
<i>Saccharum officinarum</i>	20	50	48	56	27	0	96	0.22	0.08	2.97	8.93	85.6	8.45
<i>Hyperthelia rufa</i>	145	88	62	20	0	6	0	0.88	0.07	3.21	9.65	71.43	7.044
<i>Pennisetum polystachion</i>	83	5	66	130	67	0	4	0.48	0.08	3.55	10.67	85.6	8.45
<i>Cyperus scariosus</i>	8	151	28	12	42	10	2	0.01	0.09	2.53	7.61	100	9.86
Totals									0.84		92.5		100

Note: Important value index = $RD+RC+RF$ where RD: Relative Density; RC: Relative Cover; RF: Relative Frequency. = $92.5 : 84 + 100 = 276.5$ or 2.76%; Simpson's Diversity Index: (Use inverse Simpson's Index)

D: $1 - \lambda$ Where $\lambda = \sum (ni/N)^2$

Where,

D = Diversity

N = total number of individuals

n = numbers of each different species (relative abundance of each species)

D: $1 - \lambda$ Where $\lambda = \sum (ni/N)^2 = 0.9$

$H' = 0.9$

3.4 Experimental Design

A total of 28 maize fields were used in 2012, fourteen maize fields were selected from each Sub county, 7 under monocrop system and 7 under intercrop system (maize grown together with other companion crops). In the first season of 2013 (2013A), 36 maize fields were used 18 maize fields per sub county, 9 under monocrop system and 9 under intercrop system. Each selected field was visited four times in each cropping season i.e. twice at vegetative stage, once at tasselling stage and once at physiological maturity. Field sizes were on average between 0.5-5 ha for both cropping systems. Maize varieties Longe 5H and Longe 6H, were commonly grown by the farmers in the study area. In the intercropped systems, the companion crops included soya bean (*Glycine max* (L.)), common beans (*Phaseolus vulgaris*), groundnuts (*Arachis hypogea*) and cassava (*Manihot esculenta*). The fields were kept weed free to avoid influence from weed growth and plant diversity.

3.5 Data Collection

3.5.1 Assessment of stem borers and natural enemies' occurrence on maize

3.5.1.1 Non destructive sampling (Leaf damage assessment)

On each sampling date, Leaf damage was evaluated on 10 randomly selected maize plants per field in both seasons. Sampling was carried out twice at vegetative stage, once at tasselling stage and once at physiological maturity of the maize ears. Each selected plant was scored for stem borer leaf damage symptoms using a scale 1-6 scale following the methodology of Okoth and Kalule (1990) where 1= no symptoms; 2 =1-20%, 3 = 21-40%, 4=41-60%, 5=61-80%, 6=80-100% leaf damage.

3.5.1.2 Destructive Sampling (Larval and Pupal assessment)

In addition, ten (10) maize plants were randomly selected per field, cut at the base, and dissected to expose any larvae and/or pupae of the borers. Larvae/pupae were separated by species per field, counted and placed in wide mouth plastic jars perforated at the top. The collected larvae were reared on fresh succulent maize stems changed at two day intervals in Kilner jars perforated at the top with a fine mesh in the laboratory until borer pupation or parasitoid emergence following the ICIPE stem borer diagnostic procedures (2005).

When changing the diet, dead larvae were removed, placed in small round plastic containers in the laboratory and monitored for emergence of the parasitoids. Borer pupae and parasitoid cocoons from the dissection were kept individually in small round plastic containers with perforated lids for adult moth or parasitoid emergence. The parasitoids that emerged from the borer larvae and pupae were counted and categorised into species; unidentified parasitoids were starved to death and then preserved in 70% alcohol for later morphological identification.

The pupae collected during dissection and those that pupated from the unparasitized larvae for each field were placed on wet tissue paper in a plastic petri dish perforated at the top and reared until the emergence of the adult stem borer. The adult stem borer that emerged were fed on plain water soaked in cotton wool placed on the sides of the plastic petri dishes in the rearing cage for two days for the proper development of the adult, then starved to death for another 4-5 days depending on the species, the dead adults borers were identified basing on external morphological features (wing pattern, antennal type and genitalia) (ICIPE stem borer diagnostic procedures 2005).

3.5.2 Assessment of the relative occurrence of stem borers and their natural enemies on wild grasses surrounding maize fields

In each maize field, two transect lines were made perpendicular to the side bordering the grasses to cover a distance of up to 500 m into the grass. A total of 10 mats (individual grass stamp) per grass species were sampled (5 mats per transect) in both seasons.

For each mat, 10 tillers (giving a total of 50 tillers per grass species per field) randomly selected were dissected and the borer larvae/pupae or parasitoids found recorded before being taken to the laboratory for rearing as in study 1. Each selected grass mat was also scored for stem borer leaf damage symptoms as for maize damage scores as in study 1 using a scale of 1-6 scale as used on maize, where 1= no symptoms; 2 =1-20%, 3 = 21-40%, 4=41-60%, 5=61-80%, 6=80-100% leaf damage.

3.6 Data Analysis

Data were analyzed by ANOVA using the general linear model procedure of Genstat discovery edition version 2013, with cropping systems and grass type as fixed effects. For the treatments showing significant F statistics, the means were separated using SED (the standard error of the difference between sample means, $SED \times 1.96 = LSD_{5\%}$). Foliar damage was scored using a

scale of 1-6 scale for both damage on maize and the wild grasses, where 1= no symptoms; 2 =1-20%, 3 = 21-40%, 4=41-60%, 5=61-80%, 6=80-100% leaf damage adopted from Okoth and Kalule1990

CHAPTER 4 RESULTS AND DISCUSSIONS

4.0 RESULTS

4.1 Effect of cropping system on occurrence and severity of stem borers' damage on maize in 2012B and 2013A.

Table 3 shows maize stem borer occurrence in the maize monocrop and inter cropping systems respectively. In 2012B and 2013A *C. partellus* and *B. fusca* were the predominant species. Cropping system did not influence occurrence of *B. fusca* in both seasons ($P>0.05$) but influenced the occurrence of *C. partellus* in 2013A; where more larvae were found in monocropped maize plants compared to intercropped counterparts (Table 3). With regard to severity of damage on leaves, cropping system had no discernible effect in both seasons ($P>0.05$). Monocropped maize had a mean damage score of 1.64 ± 0.17 whereas the maize in the intercrop had a mean damage score of 1.59 ± 0.17 .

Table 3. Influence of cropping system on maize stem borer larval occurrence in 2012B and 2013A in Kiryandongo district

Cropping system	No. <i>Busseola fusca</i> /plant		No. <i>Chilo partellus</i> /plant	
	2012B	2013A	2012B	2013A
Monocrop	6.56	11.38	5.23	26.52
Intercrop	5.13	10.05	6.97	14.19
Mean	5.85	10.72	6.1	20.36
SED	1.00	3.00	0.80	4.20
P (at 0.05)	Ns	Ns	Ns	0.043**

Ns = not significant at $P>0.05$

4.1.1 The incidence of stemborers at the different growth stages of the maize crop

Table 4 shows the effect of sampling time (maize crop growth stages) on infestation and occurrence of stem borers in the maize fields. Generally, 2013A season had a higher infestation of stem borers for the two species compared to 2012B (Table 4). Sampling time showed significant influence ($P<0.01$) on *C. partellus* infestation of maize in both seasons.

The borers attacked maize throughout the growing seasons. There was a highly significant effect on *B. fusca* in 2012B with no significant effect in 2013A. The lowest infestation of *C. partellus* and *B. fusca* was recorded during the tasselling stage of maize in 2012B, whereas the highest infestation of *C. partellus* was during the tasseling stage in 2013 (Table 4).

Table 4. Influence of sampling time on maize stem borer occurrence in 2012B and 2013A.

Sampling time	No. <i>B. fusca</i> /plant		No. <i>C. Partellus</i> /plant	
	2012B	2013A	2012B	2013A
Vegetative stage	6.80	11.79	7.45	18.14
Tasselling stage	4.95	08.71	3.65	24.71
Physiological maturity	5.80	11.64	7.20	18.21
Mean	3.90	10.71	6.10	20.35
SED	1.25	3.86	0.93	5.09
P(at 0.05)	0.0001***	Ns	0.009***	0.002***

4.1.2. Interactive effect of cropping system and time of sampling on stem borer occurrence and severity on maize

Stem borer infestation started higher in monocrop compared to intercrop (Fig.1) until eight weeks after planting (WAP), thereafter the infestation in the monocrop decreased with time whereas that of the intercrop increased until physiological maturity (Fig. 1.) The reverse was true for leaf damage in that leaf damage increased in the intercrop system until WAP after which it decreased whereas it started highest in the monocrop but reduced until 8WAP after which it levelled off (Fig. 2.)

Q

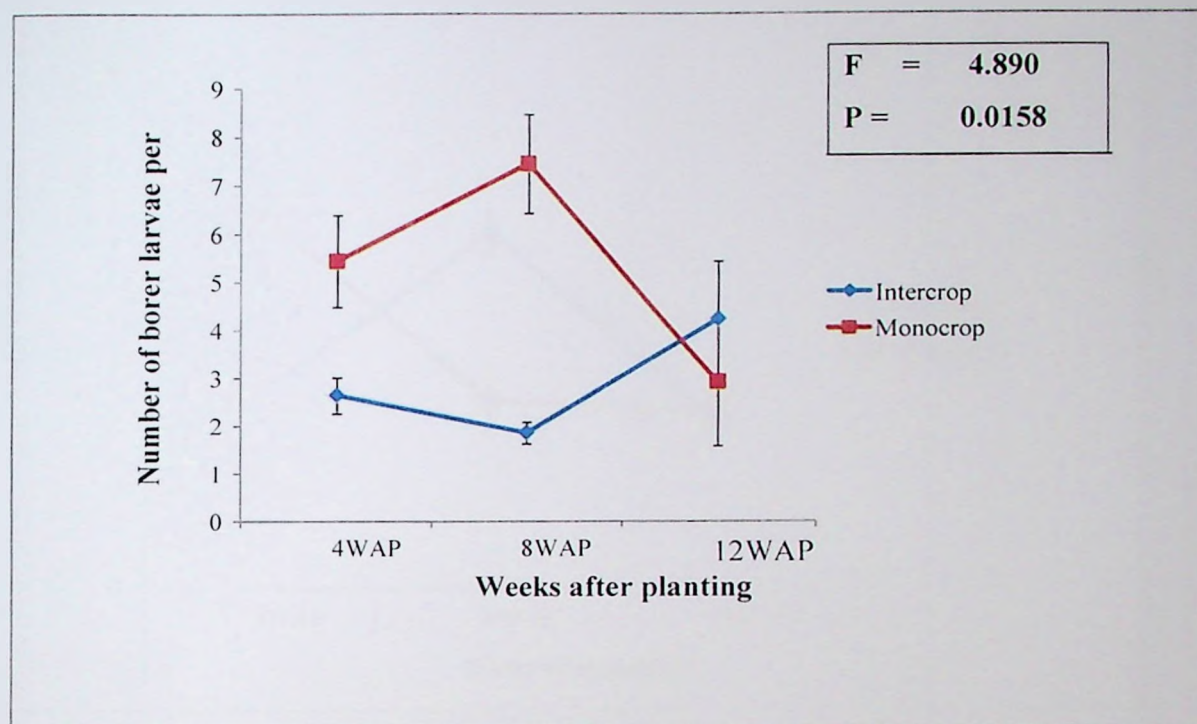


Figure 1: Occurrence of stem borer infestation on maize in the two cropping systems over different sampling time.

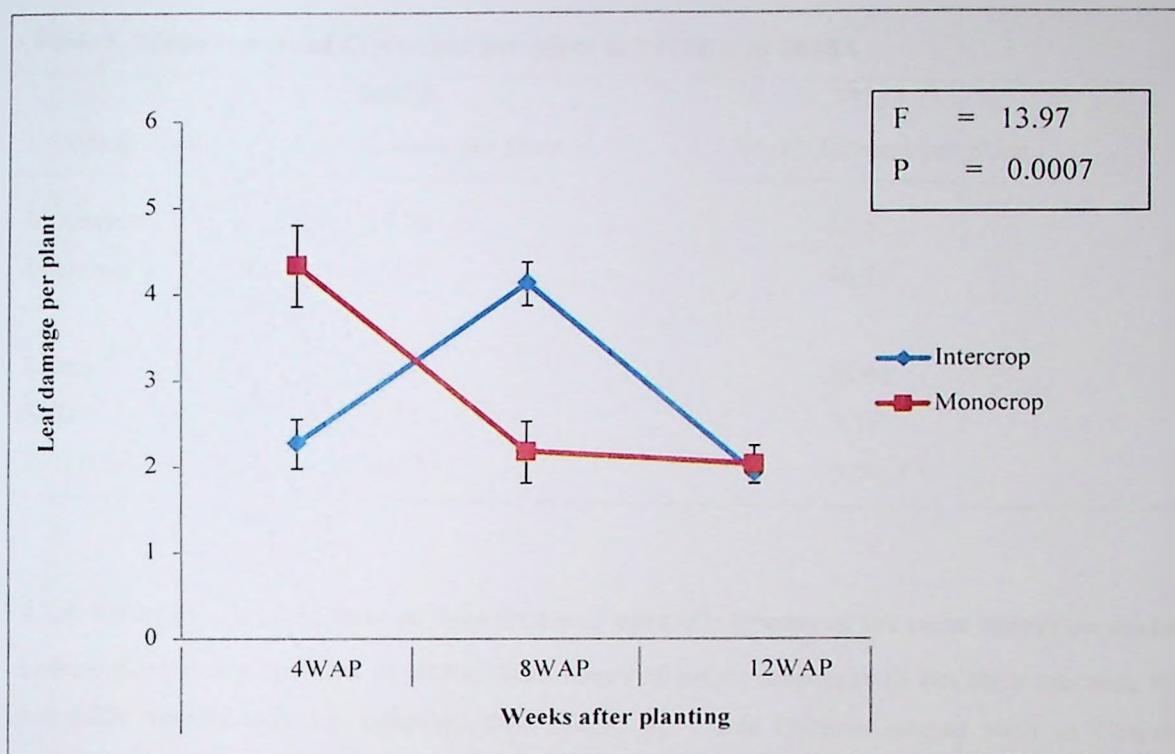


Figure 2: Stem borer leaf damage as influenced by sampling time in the two maize cropping systems

4.1.3 Effect of cropping system on occurrence of natural enemies of stem borers on the maize in 2012B and 2013A

Cotesia flavipes was the predominant parasitoid recovered from borer larvae. Cropping system had a significant effect on occurrence of *C. flavipes* in 2013A. The occurrence was higher in intercropped fields compared to the monocropped fields (Table 5). Mean counts for other parasitoids such as *C. sesamiae* were not computed because their values were too low.

Table 5. Mean counts of *C. flavipes* per plant in 2012B and 2013A

Cropping system	2012B	2013A
	No. <i>C. flavipes</i> per plant	No. <i>C. flavipes</i> per plant
Monocrop	25.50	07.52
Intercrop	35.37	46.24
Mean	30.44	26.88
SED	8.24	7.16
P (at 0.05%)	0.065***	0.001***

4.1.4. Effect of sampling time on occurrence of natural enemies of the stem borers on maize

Cotesia flavipes was present in all the three stages of maize crop growth but its occurrence did not differ significantly by sampling time (Table 6). Other *Cotesia* species such as *Cotesia sesamiae* were found in very low numbers per field and their means were not computed.

Table 6. Occurrence of *Cotesia flavipes* as influenced by sampling time

Sampling time	2012B	2013A
Vegetative stage	23.05	24.21
Tasselling stage	38.00	31.07
Physiological maturity	30.25	25.36
Mean	30.43	26.88
SED	10.1	8.8
P (at 0.05%)	Ns	Ns

4.1.5. Influence of cropping system on maize cob yield

Cropping system significantly influenced maize yield (cob weight) in both seasons ($P < 0.01$). Intercropped maize yielded up to 60% better than the monocropped counterparts (Table 7).

Table 7. Mean cob weight per plant as influenced by cropping system

Cropping system	2012B	2013A
	Cob weight/plant (gm)	Cob weight/plant(gm)
Monocrop	1.31	1.45
Intercrop	1.80	3.42
Mean	1.56	2.44
SED	0.97	0.26
P (at 0.05)	0.001***	0.001***

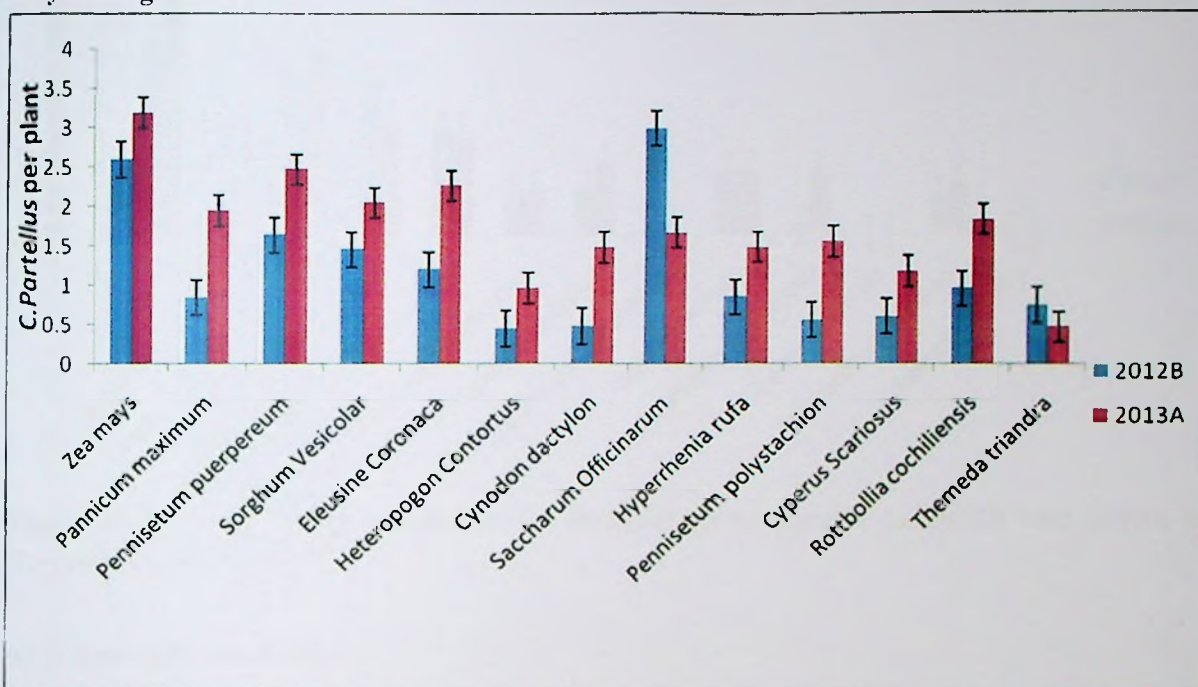
4.2. Occurrence of stem borer larvae on maize and associated grasses in the vicinity of maize fields

Stemborer larval occurrence on maize and wild grasses surrounding maize fields in 2012B and 2013A are illustrated in Figure 3a-d. Four stem borer species were found attacking maize and the wild grasses namely *Chilo partellus* Swinhoe (Pyralide), *Busseola fusca* Fuller (Noctuidae), *Sesamia calamistis* Hampson (Noctuidae) and *Eldana saccharina* Walker (Pyralidae).

4.2.1. *Chilo partellus*

Comparison of *Chilo partellus* infestation on maize crop and on the natural grasses surrounding maize fields showed that different grass species supported different larval infestations ($P < 0.05$; Appendix II). Maize sustained the highest *Chilo partellus* larval infestation followed by *Saccharum officinarum*, *Pennisetum purpureum*, *Rottboellia cochilliensis*, *Eleusine coronaca*, *Sorghum vesicolor*, and *Panicum maximum*. Other grass species including *Heteropogon contortus*, *Cynodon dactylon*, *Hyperthemia rufa*, *Pennisetum polystachion*, *Cyperus scariosus* and *Thameda triandra* sustained *Chilo partellus* larvae at low infestations. 2013A had significantly higher *C. partellus* counts on both maize and wild grasses than 2012B (Fig. 3).

Figure 3: *C. partellus* larval infestation on different grass species in 2012B and 2013A in Kiryandongo district



4.2.2 Buseola fusca

Similarly to *C. partellus*, *Z. mays* sustained the highest *B. fusca* infestation; however, the trend of infestation on the other grasses was different with *P. purpureum*, *S. vesicolor*, and *E. coronaca*, following maize in level of infestation (Appendix II). The other grass species supported relatively low numbers of *B. fusca*; in fact *C. scariosus* and *T. triandra* were not infested with *B. fusca* at all (Fig.4).

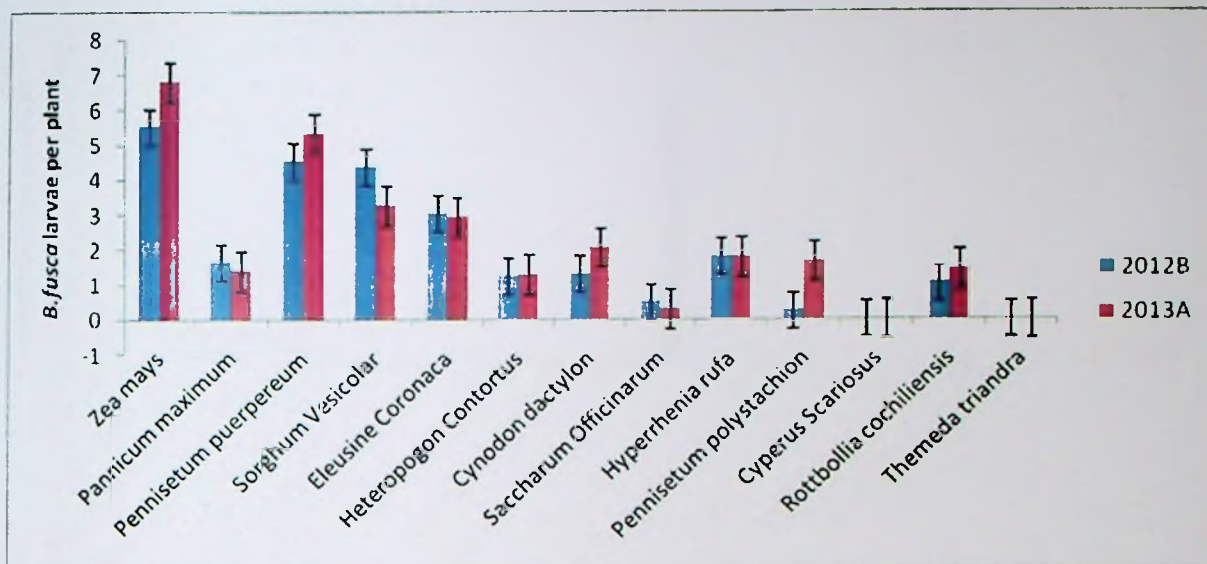


Figure 4: *B. fusca* larval infestation on different grass species in 2012B and 2013A in Kiryandongo district

4.2.3 *Sesamia calamistis*

Sesamia calamistis occurred in very low numbers on maize but in relatively higher numbers on some of the other grasses. *Sesamia calamistis* occurred highest on *Hyperhenia rufa*, followed by *Saccharum officinarum*, *Pennisetum purpureum*, and *Pennisetum polystachion* and on *Pannicum maximum* in both seasons (Fig. 5). 2012B supported significantly higher numbers of *S. calamistis* larvae compared to 2013A.

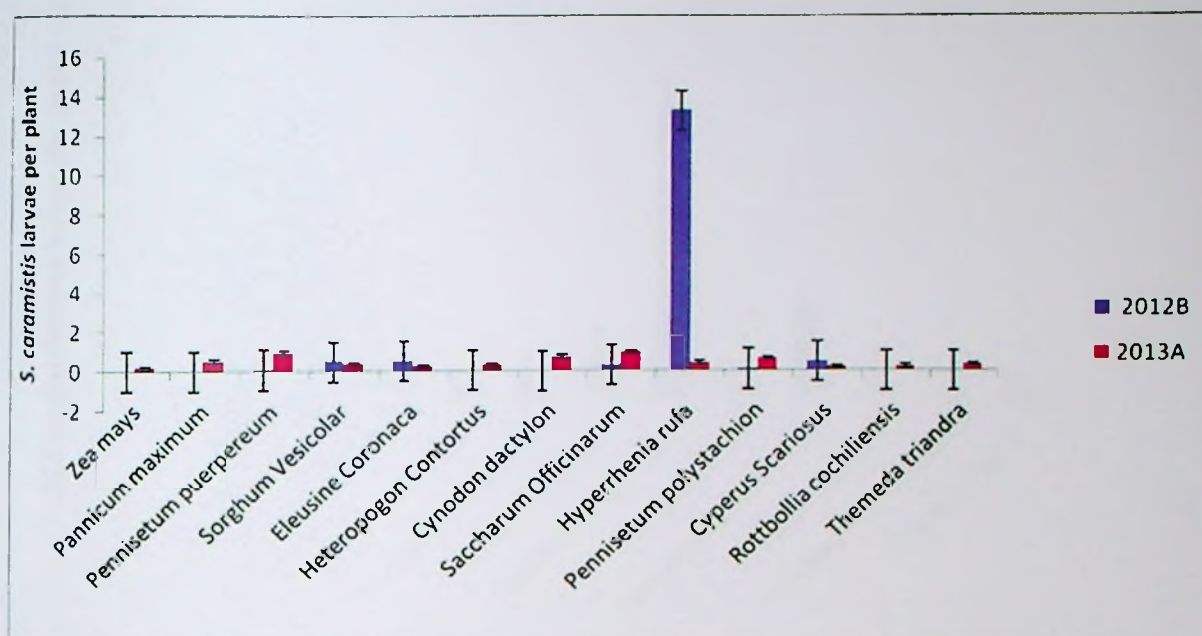


Figure 5: *Sesamia calamistis* larval infestation on different grass species in 2012B and 2013A in Kiryandongo district

4.2.4 *Eldana sacharina*

Twelve grass species were recorded as hosts of *E. sacharina* and the infestation was highest on *Saccharum officinarum* with an average of 3.5 larvae per plant. The other preferred grass species were *Pennisetum polystachion*, *Cynodon dactylon*, *Panicum maximum*, *Pennisetum purpureum*, and *Sorghum vesicular*. 2012B supported significantly higher *E.sacharina* infestations than 2013A (Fig. 6).

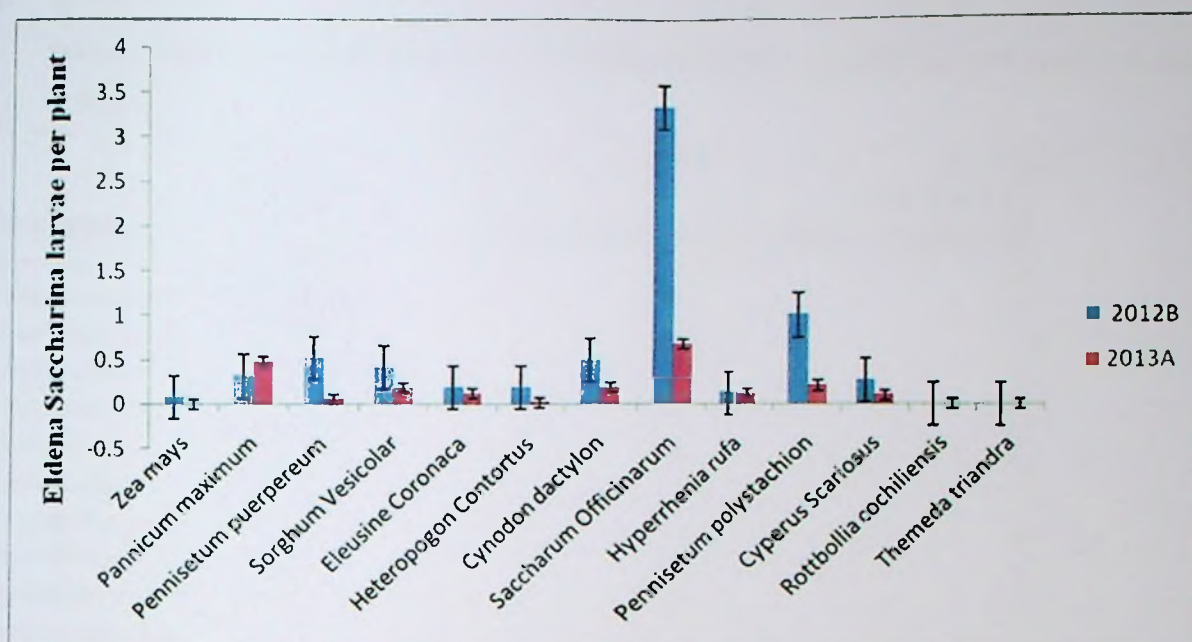


Figure 6: *Eldana saccharina* larval infestation on different grass species in 2012B and 2013A in Kiryandongo district.

4.3 Occurrence of stem borer larval natural enemies on maize vs. wild grasses in the vicinity

Cotesia flavipes (Hymenoptera: Braconidae) was the most abundant natural enemy parasitising stem borers. *Cotesia sesame* only occurred at negligible levels. Generally, larval parasitism was highest in 2012B compared to 2013A. In 2012B, *Hyperthernia rufa* supported the highest number of *C. flavipes* with an average of 36.4 parasitoids per plant followed by *S. vesicular* 30.9, *Z. mays* 29.7, *R. cochiliensis* 28.8 and *P. purpureum* 26.8 (Table 8). In 2013A, the highest *C. flavipes* counts were recorded on *S. officinarum* with a mean of 34.4, followed by *P. maximum* 19.4, *Z. mays* 19.3, *S. vesicolor* 17.7, *P. purpureum* 17.0, and *E. coronaca* 16.3 (Table 8).

Table 8: Occurrence of stem borer larval natural enemies on maize vs. wild grasses in the vicinity

Grass species	2012B	2013A
	No of <i>Cotesia flavipes</i> /plant	No of <i>Cotesia flavipes</i> /plant
<i>Zea mays</i>	27.9	19.3
<i>Panicum maximum</i>	21.3	19.4
<i>Pennisetum purpureum</i>	26.8	17
<i>Sorghum vesicolor</i>	30.9	17.7
<i>Eleusine coronaca</i>	25.1	16.3
<i>Heteropogon contortus</i>	4.1	7.8
<i>Cynodon dactylon</i>	1.1	11.5
<i>Saccharum officinarum</i>	25.3	34.4
<i>Hyperthenea rufa</i>	36.4	14.7
<i>Pennisetum polystachion</i>	7.3	12.9
<i>Cyperus scariosus</i>	13.1	7.9
<i>Rotboellia cochilliensis</i>	28.8	18.5
<i>Thamela Triandra</i>	0	4.2
Mean	19.2	15.5
SED	1.58	1.38
P(0.05)	0.021**	0.016**

4.4.DISCUSSION OF RESULTS

4.4.1 Effect of cropping system on Borer and natural enemy occurrence

Chilo Partellus (Lepidoptera: Pyralidae) was the most dominant borer species on maize in the two cropping systems. This study confirmed reports by Kauma *et al* (2000), as well as earlier ones by Hussein *et al.* (1997) that this invasive borer species is replacing *Busseola fusca* and other native borer species in Uganda. Other than *C. partellus* and *B. fusca*, other borer species occurred in relatively lower numbers on maize. This corroborates results of Okoth and Kalule (1990).

The highest borer infestation occurred in 2013A. This was probably because in 2013A, the first rains occurred earlier in February inducing borer larvae to emerge from diapause earlier (Usua, 1970, Chabi *et al* 2005) and hence the faster build-up of the pest population. Thus, maize seedlings planted within the first month after onset of rains in this season were more likely to be attacked severely by first generation larvae as stipulated by Swaine (1957). Also, the seasonal fluctuation of these stems borers may have been influenced by the extent of rainfall as stipulated by Ndemah (1999).

There were significant differences in borer infestation trends in maize monocrop vs. intercrop systems. Tahvanainen and Root (1972) proposed that intercropping lowers pest densities by reducing immigration into the crop or increases emigration from the field. The observed difference in stem borers populations in this study with intercrops having relatively lower initial infestation compared to the monocrops in both seasons could be due to this reason.

Results of this study support the hypothesis that maize borers oviposit between the leaf sheath and the stem for *Busseola fusca* or on the leaf and stem surfaces for *Chilo partellus*, first larval instars migrate to the whorl, then bore into the stem after feeding on the leaf whorl causing window panes or disperses to other plants. The presence of a non-host plant, eg. Cassava, very likely reduces the chances of the dispersing larvae to land on a suitable host thereby increasing larval mortality. This might be the reason for lower borer (*C. partellus*) larval counts in maize intercropped compared to monocropped systems in this study. Similarly, Chabi *et al.*, 2005 showed lower larval densities of *Busseola fusca* in intercropped fields compared to the monocropped fields. They concluded that the presence of the non-host plants reduced the host finding ability of the ovipositing female moths. Hence, in intercropping systems with non-host

plants, migration-related mortality of young larvae may be expected to be higher as a result of reduced host finding.

In this study, *C. partellus* and *B. fusca* were found infesting maize from vegetative stage to physiological maturity; supporting previous observations by Okoth (1990), Kalule *et al.* (1994) and Hussein *et al.* (1997) that *Chilo partellus* and *Busseola fusca* attack maize from the second week after emergence till physiological maturity with the highest level of destruction in the second and eighth week after maize emergence which lies within the three sampling rounds of the present study.

Differences in larval densities between cropping systems were more distinct earlier in the season, during the vegetative than reproductive stages of maize. This supports the hypothesis of low initial infestation in intercrops vs. monocrops which can be explained by physical or chemical barriers from the non-host crop (Khan *et al.* 1997). Leaf damage followed the somewhat similar trend but was unexpectedly higher at 8WAP in intercropped maize than monocropped counterparts. This could be explained by the fact that once the maize host was located, then the microclimate provided by the intercrop favoured more damage on the crop.

In both 2012B and 2013A the yield of maize was higher in the intercrops systems as compared to the monocropped fields. This may be explained by the fact that in the study area maize was often intercropped with legumes which may have improved the quality of the soil through nitrogen fixation and provision of adequate soil cover (Chabi *et al.*, 2005).

The study showed that *Cotesia flavipes* was the most dominant larval parasitoid of the stem borers. This corroborates results by Ndemah *et al.* (2001), Chabi *et al.* (2005) and Kauma *et al.* (2000), who found *Cotesia flavipes* as the most dominant larval parasitoid in their studies. The results of this study showed intercropped fields to have higher levels of *C. flavipes* compared to the monocrops corroborating results by Schulthess *et al.* (2004) and Chabi *et al.* (2005).

4.4.2 Comparison of occurrence of borers and natural enemies on different associated grass species.

The second objective of this study was to quantify the dynamics of occurrence of the stem borer species (*Chilo partellus*, *Busseolae fusca*, *Sesamia calamistis*, and *Eldena saccharina*) on maize and associated grasses. Studies elsewhere had shown that most cereals especially maize are often

grown in small fields surrounded by wild host plants of lepidopterous stem borers (Mailafiya *et al.* 2009, 2010). This study also found this to be true for Kiryandongo with twelve species of grasses recorded in the vicinity of maize fields. The results showed *C. partellus*, *B. fusca*, *S. calamistis* and *E. saccharina* infesting maize and associated grasses, confirming earlier reports by Seshu Reddy (1983), Overholt *et al.* (2001), and Guofa *et al.* (2002) with *C. partellus* and *Busseola fusca* dominating. *Hyperrhenia rufa*, *Pennisetum purpureum*, *Pennisetum polystachion*, *Rottobolia cochiliensis*, *Thameda triandra*, *Panicum maximum*, *Cynodon dactylon*, *Eleusine coronaca*, *Sorghum vesicular*, *Cyperus scariosus*, *Saccharum officinarum*, and *Heteropogon contortus* were all found to host the borer species, although to varying levels. *Chilo partellus* confirmed its polyphagous and invasive nature by being found infesting all the grasses, while *Busseola fusca* infested ten of the thirteen hosts. *Eldana saccharina* also infested ten and *S. calamistis* infested all the thirteen grass species albeit at low levels. These results also agree with conclusions of Kauma *et al.*, (2000) that stem borers are present all year round because several grass species serve as reservoirs. These results on the host range of the four stem borers are also in line with findings of Khan *et al.* (1997). The variability in host preference by the different borers may be explained by adult preferences for certain plant species based on chemical aspects that provide cues for oviposition or specific structural characteristics that will maximize larval growth and development, such as plant size, proximity to other host plants, and availability of specific microclimate conditions (Thompson & Pellmyr 1991; Haribal & Renwick 1998).

With regard to the comparative occurrence of larval parasitoids on maize and the associated grasses, *C. flavipes* was the most dominant larval parasitoid obtained in the study parasitizing all stem borer species on maize and the other grasses. Cugala *et al.* (1999) and Kauma, (2000), also had similar findings. Results of this study differed from the earlier reports by Ngi-song *et al.* (1995) who had shown *Busseola fusca* and *Eldana saccharina* to be unsuitable for the development of *C. flavipes*. *Cotesia flavipes* abundance in borers in the different grasses was variable but with appreciable numbers found in most of the grasses.

Earlier studies by Overholt *et al.* (1994) had showed that the indigenous parasitoid *Cotesia sesamiae* Cameron (Braconidae) was the commonest and parasitized *C. partellus*, *B. fusca*, and *S. calamistis*. However, in the study area the trend was different, with low recordings of *C. sesamiae* on all the grasses. However, the results are in agreement with findings of Kalule and

Ebellu (1997) who also observed very low parasitism by *C. sesamiae*. As such, reports that *C. flavipes* has a higher searching capacity and is a more efficient parasitoid (Sallam *et al.*, 1999) may be true. This may indicate that *C. flavipes* is displacing the less aggressive indigenous parasitoid.

Although there is an increasing threat in the form of loss in crop biodiversity, the findings indicate that in the study area, records for grassland species richness lie within the range reported for most East African forests grasslands (e.g. Linder 2001) and the indices are in line with acceptable grass diversity research findings (Githae *et al.* 2007). However, this may only be true for this part of Uganda which is known to be still sparsely populated (Rwaboogo, 1997/1998).

CHAPTER 5

5.0 General Discussions, Conclusion and Recommendations

5.1 General discussion

There are four already documented lepidopteran stem borers infesting maize throughout the growth cycle in Uganda. As such, control strategy for the borers should be preventative, initiated as early as possible. Results of the study show that intercropping offers a foundation upon which other control measures can be built. This is because though intercropped (with legumes) did not prevent leaf damage, it was shown to favour natural enemies of stem borers as well increase maize yields. These are key factors in sustainable integrated pest management systems.

Implications of the results of the occurrence of stem borers and their natural enemies on grasses in maize systems present a dilemma. The grasses sustained appreciable levels of the stem borers as well as the natural enemies. The natural enemies probably responding to the numerical aspects of the borers. Also, there was no advantage in larval parasitoid diversity from the grass species sampled. This shows that in order to exploit grasses in management of borers on maize, further research is needed, especially on host suitability of the grasses. This would help select for grasses that although they host the borers, reduce fitness of the borers in the long run. Moreover, the scope of this study was limited to larval parasitoids but the grasses may be having greater impact via predators including other arthropods and birds.

5.2 Conclusions

With respect to the set objectives, the results of the study showed that cropping system influenced occurrence of *Chilo partellus* and the larval parasitoid *Cotesia flavipes* on maize. The maize intercrop system consistently increased *C. flavipes* occurrence on maize as well as yield. Secondly, the results showed that there were variable levels of occurrence of maize stem borers and the studied larval parasitoids on maize and grasses occurring together in the landscape in the study area in Uganda. Nevertheless, maize was among the most favoured hosts of *Chilo partellus* and *Busseola fusca* larvae.

5.3. Recommendations

From the results of the study, it is recommended that:

Intercropping with legumes should be considered in an integrated management strategy for maize stem borers in Uganda and for best management results control measures for the stem borer should be instituted as early as two weeks after germination

Follow up research be instituted on *Hyperrhenia rufa*, *Sorghum vesicolar*, *Rottobolia cochiliensis* and *Saccharum officinarum* and *Panicum maximum* for **exploitation as trap crops** for the key stem borers for sustainable management of the pests on maize

To promote larval parasitoids of stem borers, farmers can incorporate *Hyperrhenia rufa*, *Sorghum vesicolar*, *Rottobolia cochiliensis* and *Saccharum officinarum* and *Panicum maximum* either as trap crops or field border attractants in the already existing maize pest management systems.

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APPENDICES

Appendix 1: summary of analysis of variance(mean squares and f-values) for the cropping system and sampling round(maize crop growth stage) on the means of stem borer larvae and their natural enemies per plant for 2012 and 2013

Source of Variation	Degrees of freedom (d.f)	Mean									
		Mean <i>B. Fusca</i> Larvae		<i>C. partellus</i> larvae		Mean <i>Cotesia Flavipes</i>		Mean leaf damage		Mean cob weight	
		Mean square	F-value	Mean square	F-value	Mean square	F-value	Mean square	F-value	Mean square	F-value
2012											
Cropping system(C)	1	30.8	0.98	45.07	2.89	1460.3	0.72	0	0.09		
Sampling round(S)	2	17.2	0.54	90.35	5.19*	1118.0		0.32	12.2		
CXS	2	9.52	0.3	19.3	1.11	1082.3	0.53	0.19	0.73		
Error	54	31.6		17.4		2037.5		0.26			
2013											
Cropping system(C)	1	18.6	0.09	1597.2	4.39*	15737	15*	40.61	29.76	40.61	29.76
Sampling round(S)	2	42.1	0.2	199.4	0.55	188.9	0.17	8.4	14.1	62.5	48.8
CXS	2	834.6	3.99*	975.02	2.68*	35.43	0.33	12.86	9.4*	0.08	0.39
Error	36	208.7		365.5		1075.9		0.59		1.36	0.2
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Appendix 11: Summary of analysis of variance (Mean squares and F-values) for the Cropping system and sampling round on maize (maize crop growth stage) and Associated grass species on the means of stem borer larvae and their Natural enemies per plant for 2012 and 2013

Source of variation	Degrees of freedom (d.f)	Mean											
		Mean <i>B.Fusca</i> Larvae		<i>C.partellus</i> larvae		Mean <i>Sesamia calamistis</i>		Mean <i>Eldena Saccharina</i>		Mean <i>Cotesia Flavipes</i>		Mean leaf damage	
		Mean square	F-value	Mean square	F-value	Mean square	F-value	Mean square	F-value	Mean square	F-value	Mean square	F-value
2012													
Cropping system(C)	1	14.96	0.63	7.35	0.22	12.13	5.56*	2.33	1.18	431.5	0.35	5.33	15.22
Sampling round(S)	2	94.72	3.98*	137.69	4.19*	32.57	14.93	6.08	3.07*	8345	6.77	1.14	3.35**
Grass species(G)	12	172.78	7.27	75.07	2.28*	63.94	29.31	3.07	1.55	2495	2.02	0.35	1.01
CXSG	14	39.47	1.66	18.91	0.58	1.27	0.58	1.15	0.58	809.8	0.66	0.17	0.48
Error	314	23.75		32.87		2.18		1.98		1233		0.35	
2013													
Cropping system(C)	1	12.01	0.48	5.73	0.19	12.67	6.66	4.76	2.97	593.2	0.44	4.46	14.83

Sampling round(S)	2	88.69	3.52**	142.71	4.62**	33.44	17.58	3.08	1.92	7783	5.71**	1.03	3.43**
Grass													
species(G)	12	4.55	0.18	65.23	2.11*	4.04	2.12*	3.32	2.07	1686	1.24	1.34	4.47**
CXSXG	14	0.15	0.51	22.86	0.82	1.1	0.69	1.26	0.66	822.97	8.6		
Error	358	25.22		30.88		1.6		1.6		1.9			
												0.3	

*Significance at $P < 0.05$; ** Significance at $P < 0.01$; and *** Significance at $P < 0.001$; Sampling round = crop growth stage

Appendix III: Stem borer occurrence on maize and associated grasses within the vicinity of maize fields

Grasses	Chilo partellus $\pm$ SD		Busseolae fusca $\pm$ SD		Eldena Saccharina $\pm$ SD		Sesamia Calamitis $\pm$ SD		Overall mean	
	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A	2012B	2013A
<i>Zea Mays</i>	6.2 $\pm$ 0.7	16 $\pm$ 0.0	5.5 $\pm$ 0.6	6.8 $\pm$ 0.0	0.8 $\pm$ 0.6	0.0 $\pm$ 0.1	0.0 $\pm$ 0.2	0.2 $\pm$ 0.2	4.2	5.8
<i>Panicum maximum</i>	6.2 $\pm$ 0.6	6.3 $\pm$ 0.0	1.6 $\pm$ 0.5	3.4 $\pm$ 0.0	0.3 $\pm$ 0.1	0.5 $\pm$ 0.1	0.1 $\pm$ 0.2	0.6 $\pm$ 0.2	2.1	2.8
<i>Pennisetum purpureum</i>	5.4 $\pm$ 0.6	4.2 $\pm$ 0.0	5.3 $\pm$ 0.6	2.3 $\pm$ 0.0	0.5 $\pm$ 0.1	0.1 $\pm$ 0.1	0.5 $\pm$ 0.2	1.0 $\pm$ 0.2	2.9	1.9
<i>Sorghum Vesicolor</i>	5.3 $\pm$ 0.7	4.9 $\pm$ 0.0	6.2 $\pm$ 0.7	3.3 $\pm$ 0.0	0.5 $\pm$ 0.2	0.2 $\pm$ 0.1	0.5 $\pm$ 0.2	0.4 $\pm$ 0.2	3.1	2.2
<i>Eleusine Coronaca</i>	7.0 $\pm$ 0.7	4.8 $\pm$ 0.0	2.0 $\pm$ 0.7	2.9 $\pm$ 0.0	0.2 $\pm$ 0.1	0.1 $\pm$ 0.1	0.1 $\pm$ 0.2	0.3 $\pm$ 0.2	2.3	2
<i>Heteropogon Contortus</i>	3.1 $\pm$ 1.4	2.4 $\pm$ 0.0	1.3 $\pm$ 1.3	1.3 $\pm$ 0.0	0.2 $\pm$ 0.3	0.02 $\pm$ 0.1	0.0 $\pm$ 0.3	0.3 $\pm$ 0.2	1.3	1
<i>Cynodon Dactylon</i>	5.0 $\pm$ 1.3	2.7 $\pm$ 0.0	1.3 $\pm$ 1.2	2.1 $\pm$ 0.0	0.5 $\pm$ 0.3	0.2 $\pm$ 0.1	0.3 $\pm$ 0.3	0.8 $\pm$ 0.2	1.8	1.5
<i>Saccharum Officinarum</i>	1.3 $\pm$ 3.2	4.0 $\pm$ 0.0	7.0 $\pm$ 2.9	1.2 $\pm$ 0.0	3.3 $\pm$ 0.7	0.7 $\pm$ 0.2	13.8 $\pm$ 0.8	1.0 $\pm$ 0.3	6.4	1.7
<i>Hyperthemia rufa</i>	5.7 $\pm$ 1.3	2.6 $\pm$ 0.0	1.8 $\pm$ 1.2	1.8 $\pm$ 0.0	0.1 $\pm$ 0.3	0.1 $\pm$ 0.1	0.1 $\pm$ 0.3	0.5 $\pm$ 0.2	1.9	1.3
<i>Pennisetum polystachion</i>	3.0 $\pm$ 1.8	2.8 $\pm$ 0.0	0.3 $\pm$ 1.6	1.7 $\pm$ 0.0	1.0 $\pm$ 0.4	0.2 $\pm$ 0.1	0.5 $\pm$ 0.4	0.7 $\pm$ 0.2	1.2	1.4
<i>Cyperus Scariosus</i>	3.7 $\pm$ 1.3	3.6 $\pm$ 0.0	1.0 $\pm$ 1.2	2.1 $\pm$ 0.0	0.3 $\pm$ 0.3	0.0 $\pm$ 0.1	0.0 $\pm$ 0.3	0.3 $\pm$ 0.2	1.3	1.5
<i>Rottboellia Cochilliensis</i>	12.9 $\pm$ 2.2	1.3 $\pm$ 0.0	0.0 $\pm$ 1.9	3.7 $\pm$ 0.0	0.0 $\pm$ 0.5	0.0 $\pm$ 0.4	0.0 $\pm$ 0.5	0.8 $\pm$ 0.8	3.2	1.5
<i>Themeda Triandra</i>	7.0 $\pm$ 2.8	1.7 $\pm$ 0.0	0.0 $\pm$ 2.5	1.5 $\pm$ 0.0	0.0 $\pm$ 0.6	0.0 $\pm$ 0.2	0.0 $\pm$ 0.6	0.4 $\pm$ 0.4	1.8	0.9
Mean	5.1	4.1	2.4	2.4	0.6	0.2	1.1	0.5		
P (0.05)	0.006***	0.003**	0.001	0.001***	0.01	0.009	0.001	0.1		