RELATIVE ABUNDANCE AND DISTRIBUTION OF STEM BORERS IN INTERCROPS OF Zea *mays* L., *Sorghum bicolor* L. AND THREE GRAMINAE REFUGIA IN TRANS-NZOIA COUNTY.

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

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To the entire family of Mr. and Mrs. S. M. Nyukuri.

ABSTRACT

This study aimed at determining the relative abundance and distribution of stem borers in intercrops of *Zea mays* L. and *Sorghum bicolor* L. and three graminae refugia due to the great economic damages caused by the stem borers to these hosts. It involved two gramineous crops: maize *Zea mays* L., sorghum *Sorghum bicolor* L. and three gramineous forages: Napier grass *Pennisetum purpureum* Schumach, Sudan grass and giant Setaria grass. These were planted both in pure and mixed stands and sampling for the borer infestation done throughout the phenology of crops. Field and laboratory bioassays were conducted to determine biophysical efficacies of the stem borers. Three stem borers were recorded: *Busseola fusca* (Fuller), *Chilo partellus* (Swinhoe) and *Sesamia calamistis* (Hampson). *Busseola fusca* was more abundant in the highlands ($1.5^{\pm}$ 0.6 larvae/plant) at 9 weeks after emergence (WAE). The *C. partellus* predominantly featured in lowlands with (2.2 ± 0.8 larvae/ plant) at 7 WAE. This was punctuated with the *S. calamistis* in the lowlands. Overally, *B. fusca* was the most prevalent with a mean of 6.4 while *S. calamistis* had the least prevalence with a mean of 2.0.The type of the gramineous refugia had a significant ($p < 0.05$) effect to the magnitude of damage caused by the stem borers. *Busseola fusca* was the most devastating species with a mean of 4.9, 3.9, 2.2 and 1.4 borers while *S. calamistis* was the least devastating with a mean of 1.1, 0.9, 0.5 and 0.6 borers in maize, sorghum, Napier and Sudan grass. However, C. *partellus* was the most devastating species in giant Setaria grass with a mean of 3.3 and *B. fusca* being the least abundant with a mean of 0.7 borer. Maize was the most damaged host indicating that it provided the best geographical requisites and nutritional attributes that were more attractive to *B. fusca*.. The type of diet fed on by the stem borers had a significant difference ($p < 0.05$) on the fecundity of the stem borers. Stem borers fed on the artificial diet had a mean egg production of 90.4 relative to 53.7 of stem borers fed on the natural diet due to balanced disaproportionality of the nutrients, typical of wild crop regimes. The number of entry and exit holes ($r = 0.059^{**}$) positively correlated with the number of larvae recovered from dissected stems. Also, the number of larvae recovered from attacked stems positively ($r = 0.074^{**}$) correlated with damage of stem borers on the leaves implying that the more the moths enter the stems, the more larvae emerge causing severe damage on the morphology of the gramineous refugia, leaves inclusive. The stem diameter had a positively correlated ($r = 0.062^{**}$) with the number of larvae recovered. The type of gramineous forage had a significant ($F = 46.3^{*}$; $p < 0.05$) effect on the damage caused by stem borers to maize and sorghum. *Pennisetum purpureum* was the most effective gramineous forage refugia with the potency of being utilized in the push – pull management strategy of the stem borers. It reduced damage caused by stem borers to 2.0% and 5.7% in maize and sorghum respectively. This implies that it had desirable traits attractive to the stem borers especially the great devastating *B. fusca* due to chemical and biophysical morphology and stem diameter. *B.fusca* was the most abundant and devastating both in the laboratory bioassays and field. Maize was the most damaged host and Napier grass was the most preferred forage refugia.

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CHAPTER ONE
INTRODUCTION

1.1 Maize and sorghum production.

Maize, *Zea mays* L. and sorghum, *Sorghum bicolor* L. Moech are cereal crops that are grown widely throughout the world in a range of agro-ecological environments. They are produced annually in larger quantities than any other conventional grain. About 50 species of maize and many sorghum environmental biotypes exist and consist of different colors, textures and grain shapes and sizes. White, yellow, brown and red are the most common maize types. The white and yellow coloured maize are more preferred for consumption while the dark brown, red brown and white are most preferred sorghum varieties.

Worldwide production of maize is 785 million tons, with the largest producer, the United States, producing 42%. Africa produces 6.5% and the largest African producers are Nigeria with nearly 8 million tons, followed by South Africa (Souza *et al.*, 2002).

It is estimated that by 2050, the demand for maize in developing countries will double, and by 2025 maize will have become the crop with the greatest production globally and in developing countries (CIMMYT & IITA, 2010). Maize is also one of the most important commodities used for food aid. Sorghum is the world's most versatile crop which is used as food for humans, forage or hay or silage for livestock. Since maize and sorghum are cheaper than other cereals such as rice and wheat, they are more affordable to the vast majority of the resource poor populations, and therefore occupy prominent positions in the third world (Leo, 2007).

During the December 2006 Abuja Summit on Food Security in Africa, African Heads of State and Government identified maize, among other crops, as a strategic commodity for achieving food security and poverty reduction and called on African countries, regional economic communities (RECs), the African Union Commission (AUC) and the New Partnership for Africa's Development (NEPAD) to enhance its maize production on the continent to achieve self-sufficiency by 2015 (AUC, 2006). In order to ensure this, it is important to understand the changing patterns in maize production on the continent. An analysis of the various forces that influence and shape the patterns of change in sub-regional maize production is important so that policies supporting increased maize production and marketing can be well articulated (De Groote, 2007).

Maize yields in Africa are quite low by world standards and average 2.7 tons/ha in 2012 compared to the global average of about 5 tons/ha. Yields have increased only marginally over the last two decades. Most of the increase in production has come from expansion in the area harvested rather than from increases in yield on none expansive acreages (Ahmad *et al*., 2000)

There are also heavy post-harvest losses due to field and lack of stem borer control strategies; poor storage and processing facilities and technologies (Shuler, 2001).

Over the past 30 years, annual world production and the area planted to sorghum have both decreased marginally from 62.8 to 59.3 million metric tons and 44.5 to 41.9 million hectares due to the stem borers devastation,outbreaks of diseases and changes in ecological condirions. Yields in 1978– 1980 and 2008–2010 were virtually the same (1400 and 1412 kilograms per hectare). However, these global figures mask wide variations at the national level. In India, for example, between 1978 and 2010 the area planted with sorghum fell from 16. 1 to 7.7 million hectares and annual production fell from 11.4 to 7.0 million metric tons, but yields increased by 40% from 689 (in 1978–80) to 965 kilograms per hectare (in 2008–10) (Shuler, 2001).

1.2 Economic importance and production of maize and sorghum in Africa

Maize is the most important cereal crop in sub-Saharan Africa (SSA). It is a staple food for more than 1.2 billion people in SSA and Latin America. All parts of the crop can be used for food and non-food products. In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial products. Maize accounts for 30−50% of low-income household expenditures in Eastern and Southern Africa.

Maize was introduced into Africa in the 1500s and has since become one of Africa's dominant food crops. Like in many other regions, it is consumed as a vegetable although it is a grain crop. The grains are rich in vitamins A, C and E, carbohydrates, and essential minerals, and contain 9% protein. They are also rich in dietary fiber and calories which are a good source of energy (Ahmad *et al*., 2000).

Sorghum is the world's fifth most important cereal crop after maize, rice, wheat and barley. It is the dietary staple of more than 500 million people in more than 30 countries (Taylor, 2001).

The percentages of the seed components are endosperm (82%), embryo (12%) and seed coat (5-6%) (Blum, 2005). The plant is very high in fibre and iron, with a fairly high protein level as well. Brown-seeded types are high in testa tannins (Heiko, 2009). Much sorghum is pigmented by polyphenolic compounds which have anti-oxidant properties (ICRISAT, 2006).

Traditional foods made from sorghum include unfermented and fermented bread, porridge, couscous and snacks, as well as alcoholic beverages. Sorghum blended with wheat flour has been used over the last two decades to produce baked products, including yeast-leavened pan, hearth and flatbreads, cakes, cookies, and flour tortillas (AATF, 2012). Malt drinks and malt cocoa-based weaning foods and baby foods are popular in Nigeria (ICRISAT, 2006). Hard endosperm sorghum is used extensively in south-east Asia for noodles (AATF, 2012).

Sorghum grain is one of the major ingredients in swine, poultry and cattle feed in the America, China and Australia. Sorghum is also grown for forage; in northern India, it is very common and fed to animals fresh or as silage or hay. Sweet sorghum is used to a limited extent in producing sorghum syrup and 'jaggery' (raw sugar) in India and has recently gained importance in ethanol production (Anonymous, 2008). The protein and starch in sorghum grain are more slowly digested than those from other cereals, and slower rates of digestibility are particularly beneficial for people with diabetes. Sorghum starch is gluten-free, making sorghum a good alternative to wheat flour for individuals suffering from celiac disease (Onyango *et al*., 2000).

The productivity gain from improved cultivars more than makes up for the cost of additional inputs like fertilizer used for their cultivation. The cost–benefit ratio of production of improved cultivars ranged from 1:1.25 (in West and Central Africa) to 1:1.4 (in India). The net present value of benefits from the cultivar S 35 was estimated at US$15 million in Chad and US$4.6 million in Cameroon (AATF, 2012). The internal rate of return was 95% in Chad and 75% in Cameroon. The adoption of improved cultivars in eight Southern African Development Community member states together contributes an additional US$19 million per year in income streams (Maddoni *et al.*, 2006).

Improved varieties occupy approximately 36% of Tanzania's sorghum area. They are widely popular, mainly for their early maturity (and thus drought tolerance) and high yield of 10–38% higher than local varieties. Adoption has been stimulated by interventions by ICRISAT and local partners to strengthen local seed systems and community-based seed production (AATF, 2012).

The maize and sorghum per capita consumption is 125 kg and 90kg. Worldwide consumption of maize is more than 116 million tons, with Africa consuming 30% and SSA 21%. However, Lesotho has the largest consumption per capita with 174 kg per year. Eastern and Southern Africa uses 85% of its production as food, while Africa as a whole uses 95%, compared to other world regions that use most of its maize as animal feed (Antonio & Munoz, 2013).

Ninety percent of white maize consumption is in Africa. It fetches premium prices in Southern Africa where it represents the main staple food. Yellow maize is preferred in most parts of South America and the Caribbean. It is also the preferred animal feed in many regions as it gives a yellow color to poultry, egg yolks and animal fat (Dixon, 2000).

1.3 Economic importance and production of maize and sorghum in Kenya

Maize is an important staple and cash crop in Kenya and constitutes 80% of the diet of the country's population (Machado & Furlani, 2001)). Maize is a source of employment to majority of Kenyans both directly and indirectly (Mulaa *et al*., 2011). Over 90 % of the population depends on it. About 80% of maize is produced by small scale farmers (Hammel, 2007). The crop is planted on 1.6 million Hectares of Kenya's arable land annually (Nyamangara *et al*., 2003).Whereas the annual production is 2.8 metric tons its capita consumption is 3.2 metric tons (Anonymous, 2001). The deficit has to be made through importation Large scale farmers obtain 5-6t/ha while small scale farmers obtain 0.5-1.5 t/ha (Ogema, 2003). Average national yields range from 1.5-2.0 tons/ha (Onyango *et al*., 2000). Research station yields range from 8.0-13.0 tons, (350,000metric tons) (Ogema, 2003).A significant production of maize is in the highlands ecological zones which occupy 30% of the national maize production area (Anonymous, 2001). Because of this, maize has held a key position in Kenya's economy and nutrition for decades (Hammel, 2007).

Sorghum is used in the preparation of traditional stuffs such as unfermented and fermented bread, porridge, couscous and snacks, as well as alcoholic beverages. Sorghum blended with wheat flour has been used over the last two decades to produce baked products, including yeast-leavened pan, hearth and flatbreads, cakes, cookies, and flour tortillas (AATF, 2012).Sorghum production and processing offers employment to Kenyans both directly and indirectly (Nyamangara *et al*., 2013).

1.4 Economic importance and production of maize and sorghum in Trans-Nzoia County

The significance of maize and sorghum in households in Trans -Nzoia District cannot be overemphasized (Onyango *et al*., 2000. Other than being staple food crop, maize is a cash crop as well as source of employment both at farm and industry levels thereby directly or indirectly affecting livelihoods of many people in the County. Unfortunately, the maize and maize yields trends have been declining in the recent past (Syngenta, 2002).The cost of production of maize is often in excess of the accrued cash returns thereby discouraging its production. This has negatively impacted not only on the people of Trans-Nzoia but also those beyond the County (Syngenta, 2002).

1.5 Patterns of change in maize and sorghum production in Africa

The patterns of maize production in Africa are analyzed over a 20-year period (1991– 2011) in order to identify policy options for developing the maize sub-sector. The analysis covers each of the five sub-regions of Africa whereby national data on maize production, area harvested and yield in each member state of the sub-region are aggregated into sub-regional data. Continent-wide aggregations are complemented with similar sub-regional analyses to demonstrate the diverse patterns of change in maize production in Africa. A ‘de-composition’ method 3 is used to analyze the absolute and relative changes in total maize production, attributable to changes in area harvested and yields. Changes in maize production during the period 1991 – 2011 are decomposed into three effects, two primary effects involving area harvested (acreage) and yield (productivity) and one interaction effect. To isolate periods of real impact, the twenty-year period is divided into two ten year periods, 1991 – 2001 and 2002 – 2012 (Chidoza *et al*., 2012).

1.6 Trends in area harvested and yields of maize and sorghum in Africa

Africa harvested 30.2 million hectares of maize in 2012. This represents 18.6% of the total area harvested in the world. The total area harvested increased by 1. 5% per annum from 22.2 million hectares in 1991 to 28.2 million hectares 2011. The growth rate which was 1% in the 1991 – 2011.In absolute terms, hectares of maize harvested in Central and West African sub-regions rose from 2.1 million and 6.9 million to 6.5 million and 10.7 million in 2000-2006 and 2006-2012 respectively. The highest annual growth in area harvested occurred in the Central African sub-region (4.4%) (Manyong *et al*., 2000). The rates of growth of harvested area were faster in the Central and West African sub-regions than the North, Eastern and Southern Africa sub-regions. In fact, the growth rates in North and Southern Africa were negative 0.7and 0.4 respectively in the two-decade period Between 1991 and 2011

Sorghum yield in Africa rose marginally from 2.43 tons per hectare in 1990, to 3.57 tons per hectare in 2010 and finally to 3.73 tons per hectare in 2011. Charcosset & Horst (2005) reveals that average sorghum yields in Africa accounts for 40% of global production in 2011 falling marginally to approximately 39% of global value in 2012. Sorghum yield in Africa, which was about 2.5kg/ha (41% of the world's yield) rose to about 2.8kg/ha in 2011 (42% of the world's yield), and fell marginally to 2.7kg/ha (34% of the world's yield) in 2012 (Charcosset & Horst, 2005).

The trend of sorghum production has not been always positive especially from 2006 – 2013 (Table 1.1).

Table 1.1: Kenya's sorghum production 2006 – 2013.

Market Year	**Production**	**Unit of Measure**	**Growth Rate**
2006	140	(1000 MT)	7.69 %
2007	140	(1000 MT)	0.00 %
2008	60	(1000 MT)	-57.14 %
2009	95	(1000 MT)	58.33 %
2010	164	(1000 MT)	72.63 %
2011	200	(1000 MT)	21.95 %
2012	175	(1000 MT)	-12.50 %
2013	175	(1000 MT)	0.00 %

Units of measure (1000 MT)

(Source: Kenya, Ministry of agriculture, 2013).

1.7 Constraints to maize and sorghum production

Four species of stem borers infest maize and sorghum crops in the region, causing reported yield losses of 20–40% of the potential output. Stem borers are difficult to control, largely because of the cryptic and nocturnal habits of the adult moths and the protection provided by the stem of the host crop for immature stages. The main method of stem borer control, which is recommended to farmers by the governments' ministries of agriculture in the region, is the use of chemical pesticides. However, this is uneconomical and impractical for many resource-poor small-scale farmers (Syngenta, 2002).

Various species of stem borers rank as the most devastating maize pests in Sub-Saharan Africa (SSA) such as *Chilo partellus* (Swinhoe) (Lepidoptera:Pyralidae) and *Busseola fusca* (Fuller) (Lepidoptera:Noctuidae). They can cause 20-40% losses during cultivation. Other pests in SSA include ear borers, armyworms, cutworms, grain moths, beetles, weevils, grain borers, rootworms, stem borers and white grubs. The parasitic striga weed is another maize pest. In fact, weed-related yield losses ranging from 65 to 92% have been recorded in the Nigerian savanna alone (Wengui, 2003).

Maize diseases in SSA include downy mildew, rust, leaf blight, stalk and ear rots, leaf spot, and maize streak virus (MSV) (Syngenta, 2002). The Maize Lethal Necrosis (MLN) affected 18500 hectares of maize in 2013 (Bii, 2013). This led to farmers in the Rift Valley, the country's grain basket lose 697000 bags of maize worth Ksh.2.1 billion after affected 26000 hectares (Bii, 2013).

Hammel (2007) and Eberhard (2008) described the factors that limited maize production in Kenya and cited insect pest problems as being one of them. According to Spencer *et. al.,* (2008), about 130 insect species cause varying degrees of damage to the crop in India.

However, only about a dozen of these are important. Among the most serious insect pests of maize recoded in Kenya are the stalk borers (Breitenback *et al*., 2005).

Despite these stem attributes, many constraints affect sorghum production. These include inadequate nutrients in the soil, pH variation, extreme scarcity of rainfall and more importantly complex pest attacks especially by stem borers whose control through an integrated pest management strategy i.e. a system whereby various methods are applied to protect the crop by suppressing insect populations and limit damage is lacking. The control measures including chemical control, biocontrol, pest resistance and cultural control need to be redefined and blended succinctly (Guoyou & Smith, 2008).

Stem borers have been managed by use of cultural control measures such as end of season sanitation where the cereal stubbles are burnt to break their life cycles and push – push system.

1.8. Role of graminae refugia in push-pull insect pest management.

Push-Pull technology provides several benefits to rural families, including reduced run-off and soil erosion, enhanced soil fertility, minimized use of agrochemicals, improved food security and increased household income. Because of its ability to expand small-farm incomes, Push-Pull is being promoted by the public sector, private sector and farmer groups across Eastern Africa. More than 12,000 farmers have adopted it and another 100,000 are expected to over the next three years as the program is promoted through mass media radio broadcasts, printed materials, agricultural shows, field demonstrations and Farmer Field Schools (FFS) (Mulaa *et al*., 2011).

The development of reliable, robust, and sustainable push – pull strategy requires a clear scientific understanding of pest's biology, and behavior/chemical ecology of the interactions with its hosts, conspecifics and natural enemies (Khan *et al*, 2013).

The specific combination of components differs in each strategy according to the pest to be controlled (its specifity, sensory abilities and mobility) and the resource targeted for protection (Khan and Pickett, 2001).

1.9 Problem statement.

Maize yields are expected to fall from 22 Million bags to 17 million bags this year (2013) due to the damaging effects of stem borers threatening the country's food security (Bii, 2013). To address food shortage 619 tonnes of maize were imported in May and June (Bii, 2013).

Stem borers damage maize and sorghum causing yield loss of between 50-85% subject to the economic threshold of the pests (Khan and Pickett, 2001). Maize and sorghum are cheaper than other cereals such as rice and wheat, thus more affordable to vast majority of poor populations (Leo, 2007).They are also sources of employment both directly and indirectly. The stubbles of these cereals are fodder to livestock hence boosting milk production providing proteins to humanity (Mulaa *et al*., 2011).

Trans – Nzoia County is a net producer of maize, stereotyped ‘grain basket’ of Kenya. Thus, declining production of maize is this County threatens food security in the entire country of Kenya.

Despite the adoption of ICIPE push – pull insect pest management design, maize and sorghum are being seriously damaged by the stem borers as moths fly into maize and sorghum fields ovipositing on crops without necessarily entering these fields from the periphery to be trapped by the refugia. The larvae hatch out damaging these crops from the centre of the fields due to increased abundance and distribution of the stem borers in the hosts.

In this study, strip intercrops of food and forage intercrops were adopted to address the incidences of moths flying into the centre of maize and sorghum fields since they could be trapped by the refugia intercrops.

1.10 Justification of the studies.

Maize and sorghum are life to more than 90% of Africa’s population thereby becoming the Africa’s most important cereal food crops. To increase food security in accordance with the first [1] Millennium Development Goal [MDG], management of the stem borer species is paramount especially in Trans-Nzoia County which is the grain [maize] basket of Kenya.

The data generated by this study was envisaged to have positive impact in aiding in production of adequate food for the ever increasing Kenyan existing population on the limited arable land through emphasizing control of more devastating and abundant stem borers using the most appropriate refugia intercrop. It is against this background of understanding that this study was conceived. The overall objective was to determine the relative abundance and within host distribution of stem borers in strip intercrops maize, sorghum and three graminae refugia so as to curb the stem borer population from attaining the economic injury level thus, enhancing food security and reducing poverty levels among Kenyans. The specific objectives of this study were as follows:

1. To determine the composition, identity and geographical distribution of the stem borer complex.
2. To quantify the relative abundance and within host distribution of stem borers in intercrops of gramineous crops and forages.
3. To elucidate the magnitude of damage and yield losses caused by stem borers in intercrops.
4. To establish the efficacy of the use of most preferred refugia of stem borers in a push and pull pest management strategy.

CHAPTER TWO

LITERATURE REVIEW

2.1 The composition, identity and geographical distribution of the stem borer complex

The East African stem borers of cereals comprise of the African maize stalk borer, *B. fusca* Fuller, the spotted stalk borer, *C. partellus* (Swinhoe), the coastal stalk borer, *C. orichalcocilliellus* Strand, the sugarcane stalk borer, *Eldana saccharina* Walker and pink stalk borer, *Sesamia calamistis* Hampson (Mulaa *et al*., 2011). Of the above stalk borers, *B. fusca* and *C. partellus* are ubiquitous species occurring throughout the region (Ahmad & Javed, 2007), while the others are sporadically prevalent in Kenya.

Busseola fusca (Fuller) (Lepidoptera: Noctuidae) (Plate 2.1) is a common pest in many sub-Saharan Africa countries. In East Africa it occurs at altitudes of 1000 to over 2700 m while in Central Africa it is the predominant pest across all altitudes over 2000 m. In West Africa, it is only common on sorghum in the dry-hot zones. It is indigenous to Africa. Its distribution and pest status varies with the region. *Busseola. fusca* (Fuller) as indigenous pest of maize, sorghum and millet in Africa is widely distributed in cool humid regions above 1500 m. However, current research indicates that *B. fusca* populations also occur at relatively lower altitudes in humid altitudes in humid environments (Eizaguirre *et al*., 2006).

The spotted stem borer *C. partellus* (Swinhoe) (Lepidoptera: Pyralidae) (Plate 2.2) is an important pest of maize, sorghum, rice and sugarcane in Asia and most parts of Africa (James, 2004). The stem borer which is indigenous in Asia became established in East Africa by the early 1950s (Mugo *et al*., 2004) and is now considered to be one of the most important pests of maize and sorghum in East, Central and Southern Africa (James, 2004).The stem borer is widely distributed at altitudes below 1700 m (Amudavi *et al*., 2009) (Fig. 2.1).

Plate 2.1: Adult *B. fusca* (Fuller) (Source: Author, 2011).

Plate 2.2: Adult *C. partellus* (Swinhoe) (Source: Author, 2011).

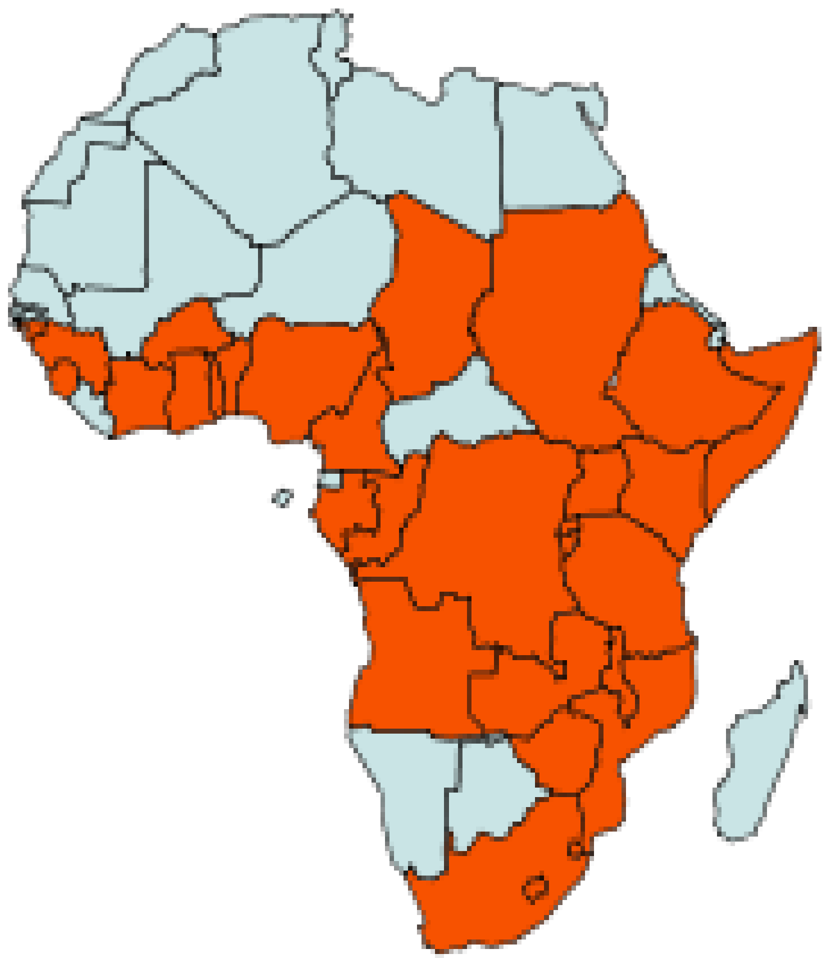

Fig 2.1: Geographical Distribution of the African maize stalk borer, *Busseola fusca* in Africa. (Source: KARI, 2011).

Key: Mid-brown – Region infested with the African stem borers

Light-green – Region not infested with African stem borers

2.2 Quantification of relative abundance and within host distribution of stem borers in strip intercrops of gramineous crops and forages.

Stem borers population is relatively lower when graminae crops are planted with potential refugia especially in push – pull designs. The infestation of stem borers is minimized per host as they attack spreads to various hosts. The population of the stem borers further declines when the crops and refugia occur in strip intercrops as the refugia is in proximity with the protected crops throughout the farm thus any stem borers flying into the field by chance will still be pulled to the adjacent refugia. Therefore strip intercropping of refugia and the cereals is more effective strategy of reducing the stem bore populations to the general equilibrium position hence reducing their economic damages (Chabi-Olaye *et al*., 2006).

When the stem borer population exceeds the economic threshold they cause serious losses when maize plants are particularly attacked at an early stage and in high densities (Khan *et al*., 2013). Mulaa *et al*., (2011) gave the reasons for the increased damage in young plants as being due to tenderness of leaves and stem which aged and toughened and thus became unsuitable for newly hatched larvae. The first generation of the larvae was thus important in terms of causing yield loss and exceeded the second generation which attacked the crop when it was already advanced in age (Muasya & Diallo, 2006).

Several scientists have reported yield loss estimates due to massive stalk borers in several countries in the African continent (De Groote, 2007; Esilaba, 2006; Muthoka *et al*., 2006). Miller (2009) when working in Nigeria recorded an increase in yield of about 26% when maize crops were adequately protected through insecticidal application against stalk borers hence, stem borer population is at minimum. Barrion (2009) established that the presence of one or two larvae per plant reduced yield by 25% in the same country thus suggesting this population level to represent the most probable economic threshold level.

In Zimbabwe, *B. fusca* infestation was observed to result in variable losses, which were either negligible or total (Muthoka *et al*., 2006).

In East Africa, losses in cereal grain yield due to stem borers ranged from 44-50% (Mugo *et al*., 2005). When a single *B. fusca* larva developed in a healthy maize plant, it reduced its yield capacity by 28% (Tabashnik *et al*., 2003), while elimination of single borers maximally enhanced yields by 35 1b/ha (Wasike, 2007). Kingi & Burgess (2004) in a survey of estimation of grain yield losses in cereals attributed 27% and 18% losses due to stalk borers in Tanzania and Kenya respectively. In Kenya, Anonymous (2005) found that about 1.2% of the total yield was reduced whenever 1% of the plants were attacked. In the Kenyan Rift Valley region, Tambi & Maina (2005) reported economic losses of Ksh. 217.20 per 90 kg in monetary terms. Kahumbu's (2012) studies yielded slightly different findings from those reported by Maddonni *et al.,* (2006). Later, Mulaa *et al., (*2011) was of the opinion that James (2004) studies left many variables uncontrolled and that their estimates were not convincing. The current studies therefore aimed at mainly quantifying the economic injury level of the borers further for better understanding of the occurrence, damage and management of the pest.

2.3 The life cycles of stem borers

The moths which give rise to the stem borers are holometabolous (Plate 2.3 and 2.4). The eggs are round, flattened and about one mm in diameter. They are usually laid in batches of 30 to 100 under leaf sheaths in a long column stretching up the stem, and may slightly be compressed by pressure from the growing stem. They are white when first laid but darken as they age. Eggs hatch in about 7 to 10 days (Potori, 2012).

Caterpillars are light or dark violet to pinkish white in colour, often with a distinctive grey tinge. They lack conspicuous hairs and look smooth and shiny, but have rows of small black spots along the body. On hatching caterpillars are blackish. They crawl up the plant into the funnel where they feed on leaves for 2 to 3 days and then either move to other plants or enter inside the maize stem (Giliomee, 2003).

After the caterpillars bore into the maize stems, they feed and grow within the stems for 2 to 3 weeks. They grow to a length of about 40 mm. When fully grown, they cut a hole in the side of the stem before pupating within the tunnel inside the maize stem (Songa, 2000).

The total larval period is usually 35 days when conditions are favourable during the growing season, but during dry and/or cold weather caterpillars enter into a resting period (diapause) of 6 months or more in stems, stubble and other plant residues. With the beginning of the rains, the caterpillars pupate within the stems (Taylor, 2002).

The larvae then make their way down to the growing point. This may be destroyed, but usually one or more larvae manage to penetrate the stem below. They will feed here, filling the feeding tunnels with frass, and after 30 to 40 days, having passed through six instars, they reach maturity. Before pupating, they bore an "escape hatch" in the side of the stem with only a thin outer layer remaining. As this dries, it forms a conspicuous

windows on the stem that indicates the presence of the pest (Odhiambo, 2002).

Pupae are shiny yellow-brown to dark brown and about 25 mm long. After 7 to14 days the adults emerge from the pupae and come out of the stem (Skinner, 2013).

The larvae may feed on tassels or on the developing cobs before penetrating the stem. Not all second-generation larvae pupate immediately, upon reaching maturity. Larvae hatching from eggs laid after mid-February invariably enter a diapause state. Having tunneled down into the lower end of the stem (even below ground level), they hibernate in the dry stubble over the next months, and only become active again in the spring to complete the life cycle (Mulaa *et al*., 2011).

The adults have a wingspan of about 25 to 35 mm. Females are generally larger than males. The forewings are light to dark brown with darker markings and the hind wings are white to greyish-brown. There is much seasonal and geographic variation with darker colouration developing in cold wet conditions (Hammel, 2007).

Adult moths of stem borers are seldom seen in fields, as they are inactive during daytime. They become active after sunset and lay their eggs during the night (Gerstl, 2002).

They have several generations in a year, so their numbers increase towards the end of the season (Wright, 2012).

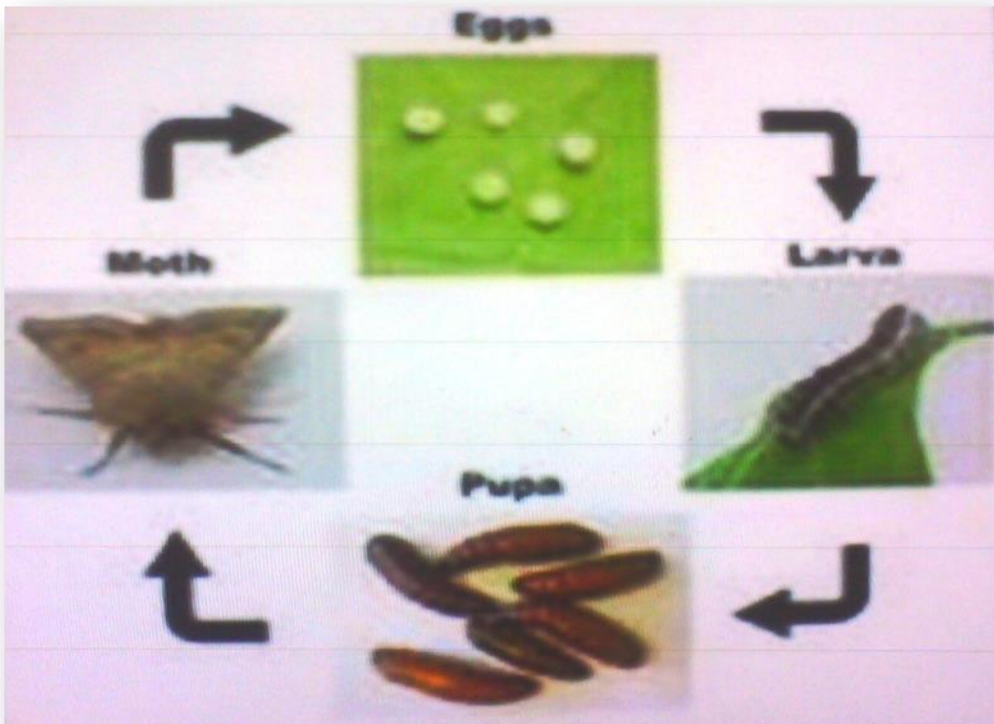

Plate 2.3: Life cycle of *C. partellus*. (Source: KARI, 2011).

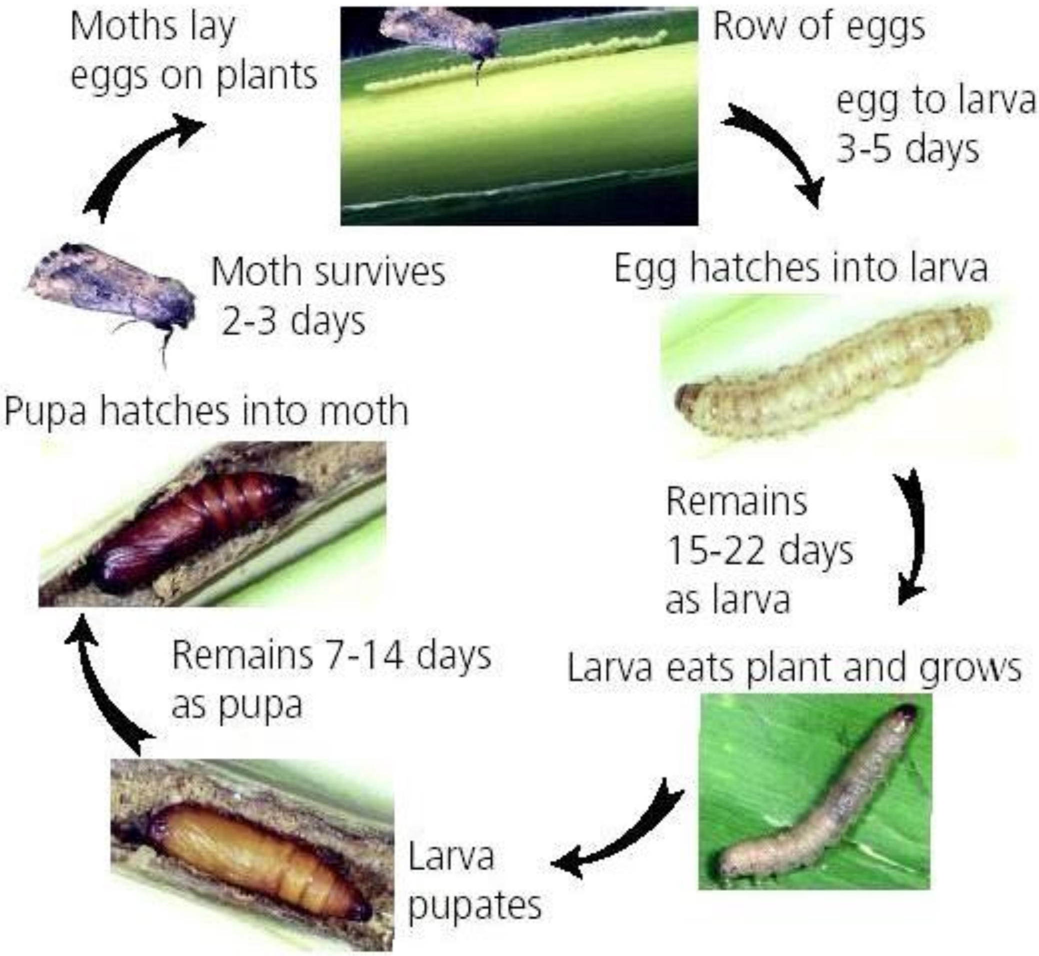

Plate 2.4: Life cycle of *B.fusca* (Source: KARI, 2011).

2.4 Damage caused by stem borers to their hosts

Damage is caused by the caterpillars, which first feed on young leaves, but then enter into the stems. During the early stage of crop growth, the caterpillars may kill the growing points of the plant, causing what is known as dead-heart condition whereby the youngest leaves can be easily hand pulled off without much effort (AAFT, 2012).

At a later stage of growth, they make extensive tunnels inside the stem. This disrupts the flow of nutrients to the grain. Tunneling weakens the stem so that it breaks and falls over. In older plants the first generation caterpillars bore in the main stem but later some of the second generation borer bore into the maize cobs. Caterpillars also tunnel into the peduncles of sorghum and millet inflorescences, and may seriously affect grain production (Shuler, 2001).

Because maize plants do not produce tillers, they are less able to tolerate stem borer attack than sorghum and pearl millet plants and the effect on grain yields is therefore greater (James, 2004).

Colonization of the plant by borers, severity of infestation and damage strongly depend on the cropping system and soil fertility, which affects the nutritional status of the plant. Stem borer damage is aggravated by the poor nutritional status of the plant. Studies on several stem borers in Africa showed that an increase in nitrogen is related to higher pest loads and tunnel damage (Mulaa *et al.*, 2011).

Grains damaged by pests such as stem borers become susceptible to infection by mouldy fungi such as *Aspergillus* spp. which produce aflatoxin, a toxic by-product extremely poisonous to people and which can lead to liver cancer (Mugo *et al*., 2004).

Stem borers damage plants by their feeding activities on the leaves and within plants causing yield loss in crops of between 44-80% depending on pest population (De Groote, 2002). Damage to the maize crop is a result of feeding activities of the larvae which begin after hatching (De Groote, 2007).

The eggs which are laid within the leaf sheaths hatch in 7-12 days into young larvae which migrate up to the stem and down into the funnel to feed on the tender, rolled up young leaves or whorl by scraping the leaf tissue (Amudavi *et al*., 2009).When damaged young leaves grow out of the funnel and unfold, they exhibit characteristic lines of small holes also known as “windows”; these “windows” run across the leaves as right angles to the main vein which is typical of early stages of stalk borer infestation (Nyukuri *et al.*, 2012 (a). This damage syndrome is depicted in the field as shown in Plates 2.5 and 2.6. Some of the larvae may penetrate downwards destroying the growing point leading to death of the central creating a “dead heart” condition (James, 2004). In case the plant dies the same larvae move to the adjacent plants. However, if the plant survives, the mature larvae bore down into the centre of the stalk where it feeds until pupation (Anonymous, 2005).

Feeding by tunneling of the stems of growing plants by larvae weakens plants resulting in lodging (Leo, 2007). Damaged plants often die through the reduction of translocation of water and minerals (De Groote, 2007). When infestation coincides with tasselling and silking stages, the moths usually lay eggs on sheaths of older leaves or on ear husk leaves (Ngugi *et al.*, 2006)). The emerging larvae in this case feed on tassels and silk thereby reducing pollination (Njihia *et al.*, 2006).

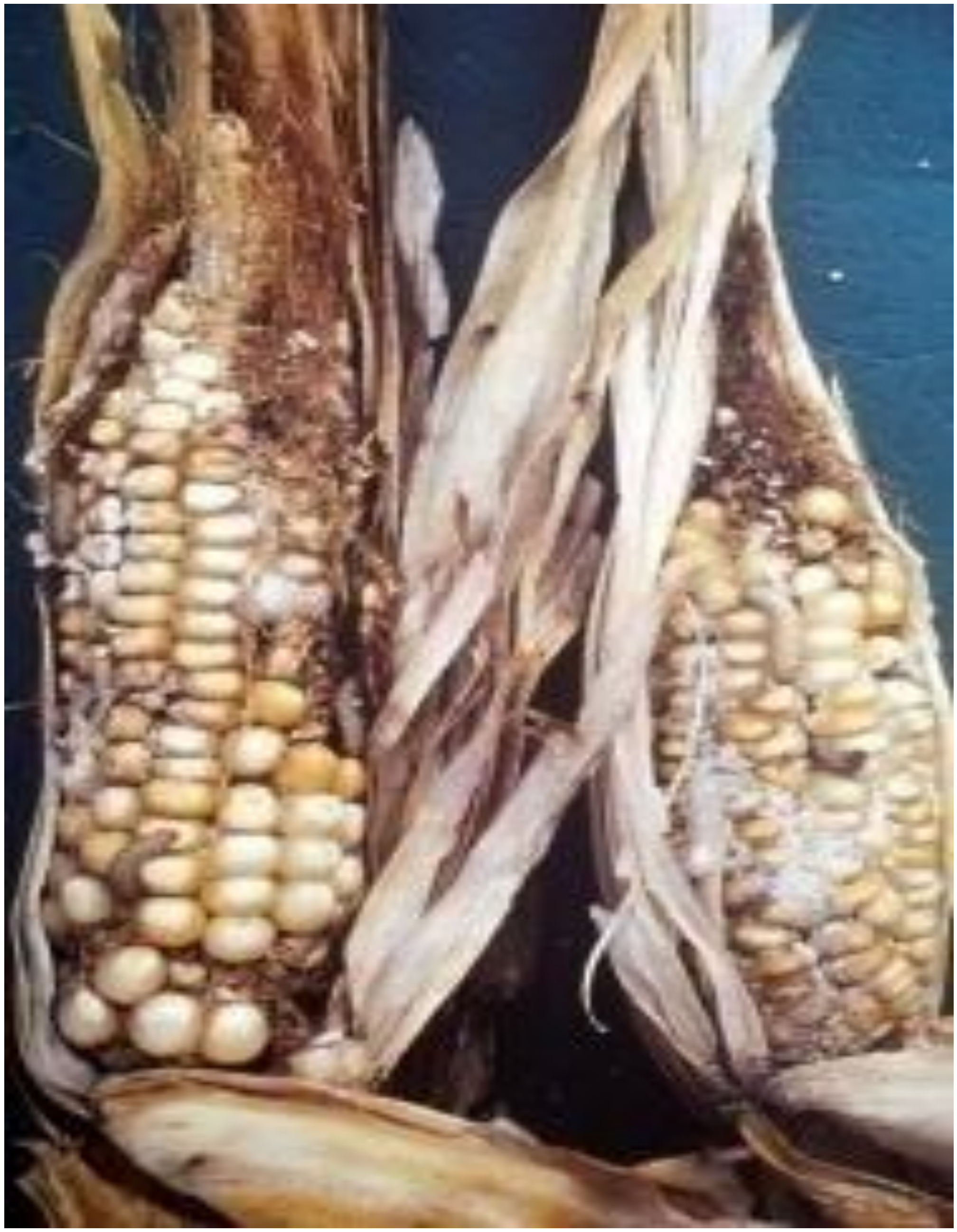

Plate 2.5: damage of stem borers to maize grains. (Source: Author, 2010).

Plate 2.6: Damage of stem borers to maize leaves. (Source: Author, 2010).

2.5 Symptoms of maize attacked by stem borers

Symptoms in maize plant include dead heart, plant death, dieback, internal feeding and presence of frass in the stems. Older caterpillars tunnel in stems, and fed on long frass-filled galleries, which weaken stems and cause breakages (Mugo *et al*., 2006).

Early warning signs in infested maize include small holes in straight lines on the youngest leaves. The affected plant stages are: flowering, vegetative growing stage and generative stage (Woodcock, 2011).

However, affected plant parts include: growing points, inflorescence, leaves seeds, grain, ear / head and stems (Mugo *et al*., 2002).

2.6 Yield losses in crops due to the stem borers.

Quantitative estimation of yield losses caused by pests has been derived from simple standardized crop loss assessment methods (CIMMYT and IITA, 2010).

According to the above listed institutes, the popular methods include: comparing yields from chemically protected crops with naturally infested ones (Tambi & Maina, 2005). Comparing yields in fields having different pest infestation loads (AUC, 2006) relating yields with artificial incidence of pests of known magnitude (Hammel, 2007) extrapolating from yields of individual plants in heavily infested fields and those which otherwise are free of infestation (James, 2004)and gathered data through literature review of expert testimony, (Kenya, MoA, 2005).

2.7 Alternative potential gramineous refugia of stem borers for push-pull system.

The most important alternative hosts which could also serve as refugia for the four major stem borers are reportedly cultivated sorghum, *S. versicolor* Anderson, *S. arundinaceum* Stapf, Napier grass (*Pennisetum purpureum* Schumach) *and Hyperrhenia rufa* Nees, Sudan grass (*Sorghum vulgare Sudanese*) and giant Setaria grass molasses grass (*Melinis minutiflora*), desmodium (*Desmodium uncinatum* and *D. intortum*) (Odhiambo, 2002). Napier grass and Sudan grass are used as refugia whereas molasses grass and desmodium repel ovipositing stem borers. Although stem borers oviposit heavily on some grasses, only few species are favourable for them to complete their life cycles (Chabi – Olaye *et al.*, 2005).

There refugia plants utilized in push-pull insect pest management drive them away from the main by emitting repellants. Both maize and sorghum stem borers are polyphagous and have many wild graminacious alternative hosts (Kenya, MoA, 2005). The wild hosts are thought to be the original hosts of stem borers in their native ecosystems. The current dogma is that wild habitats constitute reservoirs for severe pest infestation on crops. This may not apply on all pest species due to differences in races adapted to different habitats. Research shows that the natural hosts of insect pests act as trap plants which keep pest populations away from cultivated hosts (Songa *et al.,* 2002). Refugia grasses can compliment an integrated pest management (IPM) thus making the strategy less palliative. The current IPM includes: early planting, use of pest and disease tolerant varieties, use of environmentally friendly methodologies which preserve natural enemies such as selective pesticides, natural plant products, and use of push-pull strategies (Eberhard, 2008)**.**

2.8 Economics of push – pull pest management strategy.

The push-pull management strategy has contributed to food security immensely (Mulaa *et al.,* 2011). Intercropping or mixed cropping of maize, grasses and fodder legumes has enabled farmers in Kenya to increase crop yields thus improving their food security and gross benefits. This feature of the technology is suitable for mixed farming conditions which are prevalent in Trans – Nzoia County and has increased maize yields by 20 % (Mulaa *et al.,* 2011).

The principles of this strategy maximize control efficacy, efficiency, sustainability and outputs while minimizing negative environmental effects. The efficacy is improved through tandem deployment of its components (Songa, 2000).

The push – pull components are generally non- toxic therefore the strategies are integrated with biocontrol (Chabi – Olaye *et al.,* 2008). However,moths still fly over the refugia on the periphery inflicting damage to the gramineous crops.

The refugia have boosted dairy farming as they serve as livestock farming especially the Napier grass. Desmodium is a nitrogen – fixing legume, improves soil fertility and is a quality fodder and also an effective stem borer repellant (Songa, 2000).

2.9 Control of Stem borers of maize and sorghum.

In Kenya, research for control of stem borers has been intensified. The following methods have been tried and proved effective (Odhiambo 2002).

2.10 Field sanitation - This involves three aspects as explained here below:

2.10.1 Destruction of crop residues. This is important to kill the pupae left in old stems and stubble and to prevent carry-over populations. It also limits initial establishment of the pest on the following season's crops. Also burning crop residues is an effective way of killing stem borer caterpillars, but can create problems in farms where the organic content of soils is low and soil erosion is severe, since in many cases crop residues are the only organic matter added into soils in small holder farms (Kfir *et al.,* 2002).

2.10.2 Ploughing and harrowing. These practices help reduce borer populations by burying them deeply into the soil or by breaking the stems and exposing the caterpillars to natural enemies and to adverse weather conditions.

2.10.3 Slashing maize and sorghum stubble. This is complemented with cultivation by discing and ploughing can reduce larval populations by almost 100% (Kfir *et al.,* 2002).

Alternative ways to destroy diapausing caterpillars without destroying the stems are needed in areas where stems of cereals are used as building and fencing materials, fuel, bedding for livestock, or as stakes. In this case, partial burning is recommended, while the leaves are dry but the stalks are still green. Heat generated from the burning leaves kills up to 95% of stem borer caterpillars within the stems, and at the same time cures the stalks, improving their quality as building materials and making them more resistant to termite attack. Destruction of wild sorghum, which would act as alternative host, may help to reduce population upsurge (Muthoka *et al.,* 2006).

2.12 Cultural measures for stem borer management

For these to be effective, the cooperation of farmers in a region is required because moths emerging from untreated fields can infest adjacent crops.

2.13 Crop rotation

The use of short duration fallows with leguminous cover crops and grain legumes have been useful in reducing yield losses due to borers in the subsequent crop. Rotation with grain legumes (cowpea and soyabean) or leguminous cover crop pigeon pea and mucuna (*Mucuna pririens*) improved the supply of nitrogen in the soil and enhanced the yield of subsequent maize crop in the humid forest of Cameroon (Moeser & Vidal, 2005).

This leads to an improved nutritional status of the plant led to an increase in attacks by the African stalk borer at the early stages of the plant growth, but also improved plant vigour, resulting finally in a net benefit for the plant and grain yield (Chabi-Olaye *et al*., 2008).

2.14 Biological pest control.

Many natural enemies of the African stalk borer have been recorded in Africa. The most important are predatory ants, parasitic wasps and parasitic flies. Parasitic wasps may attack eggs (e.g. *Trichogramma* spp. and *Telenomus* spp.) or caterpillars (e.g. *Bracon* spp and *Cotesia sesamiae*). Tachinid flies parasitize caterpillars (James, 2004). *Cotesia sesamiae* is the most common larval parasitoid (attack caterpillars) of this stem borer on maize in eastern Africa that has been introduced in this ecozone (Chabi – Olaye *et al*., 2006).

2.15 Use of botanicals.

This includes neem products which are reported to be effective for control of stem borers, including the African maize stalk borer (Chabi-Olaye *et al*., 2006).

It is recommended that a small amount of neem powder (ground neem seeds) mixed with dry clay or sawdust at a rate of 1:1 be placed in the funnel of the plant.

One kg powder should be sufficient to treat 1500 to 2000 plants. In this method rainwater dissolves the active substances in neem powder as it gathers in the funnel and washes out the powder (Mugo *et al*., 2002). Where rainfall is irregular a liquid neem seed extract can be sprayed into the funnel (De Groote, 2007).

The treatment should be repeated every 8 to 10 days during the sensitive growing phase. Thus, roughly three treatments are required per crop. This recommendation applies only for young plants before flowering and not for older plants. Neem powder should be always applied as a mixture with inert materials (sawdust, rice hulls or dry fine clay), as the powder alone can be phototoxic (harm the plants) owing to its oil content (Eberhard, 2008).

In studies in Tanzania, aqueous seed extracts combined with extracted ground neem seeds and sawdust, applied twice to the whorl of maize leaves was as effective in controlling the African stalk borer as endosulfan (De Groote, 2007). The extract was prepared by soaking 120g of neem seeds and 120 g of sawdust in three litre of water for 12 hours. The mixture was filtered and the residue and the aqueous extract were then applied separately to the maize plants (Chabi –Olaye e*t al*., 2004).

2.16 Intercropping and habitat management.

The importance of plant biodiversity in maize agro - ecosystems for reducing borer's infestation on maize has been recognized in sub-Sahara Africa (Moeser & Vidal, 2005).

Maize intercropped with non-host crops (e.g. cassava and grain legumes) have significantly lowered stem borer damage and had higher yield than monocrop maize. The effect is variable, if the crop to be protected is not planted after the companion crops. In studies in Cameroon, maize monocrops had 3 to 9 times more stems tunneled and 1 to 3 times more cob damage than maize intercropped with non-host crops such as cowpea, cassava and soybean, which resulted in a higher yield in the intercropped maize. In the mixed cropping system maize was planted 12 to 14 days after the non-host plants (Nyukuri *et al.,* 2012 (a). Two plant arrangements were used: One maize plant was followed by a non-host plant and Strip planting in which two rows of maize were followed by two rows of a non-host crop and with one row of non-host plants as borders.

Maize yield losses due to stem borers were about 2 to 3 times higher in monocrops than in intercrops. In addition land-productivity was higher than with monocrops. The maize-cassava intercrop was the most effective in terms of land use and the most productive compared to pure maize stand with pesticide application. The net production of mixed cropping systems was economically superior to controlling stem borers with insecticide in monocropped maize (Chabi-Olaye *et al*, 2005; Chabi-Olaye *et al*, 2008).

Studies in Kenya suggested that intercropping maize and/or sorghum with cowpeas reduced damage caused by the African stalk borer (Mulaa *et al*., 2011). Trials in Eritrea showed that sorghum intercropped with haricot beans, cowpea, desmodium and Dolichos lablab had much lower dead heart damage compared to pure stand sorghum (Chabi – Olaye *et al*., 2004).

2.17 Push-Pull Strategy of stem borer management

This was developed by scientists of International Centre of Insect Physiology and Ecology (ICIPE) in Kenya and those of Rothamsted Research in the United Kingdom in collaboration with other research organizations in eastern Africa. They used repellent plants to deter the pest from the main crop (Chamberlain *et al*., 2006). The strategy involves use of intercrops and refugia. The refugia used in pull – push strategy have inherent ability of not allowing development of trapped stem – borers, thus reducing the number of trapped insects. The strategy also attempts to fully exploit the natural enemies in the cereal farming system (Cook *et al.,* 2007).

The term "pull –push " was first conceived as a strategy for insect pest management by Khan *et al.*,(2000).They investigated the use of repellant and attractive stimuli, deployed in tandem to manipulate the distribution of *Helioverpa* spp. in cotton to reduce reliance on insecticides, to which moths are becoming resistant. The concept was later formalized and redefined by Khan *et al*., (2000) who termed the strategy "stimulo – deterrent" diversion while developing alternatives to insecticides to control onion fly, *Delia antique* (Khan *et al*., 2000).

Among push – pull strategies under development or used in practice for insect pest control, the most successful example of pull – pull strategy currently being used by farmers was developed in East Africa for controlling stem – borers on cereal crops (Khan *et al*., 2006).This strategy was developed using technologies appropriate to resource poor farmers and has shown a high adoption rate and spontaneous technology transfer by farmers, resulting in significant impact on food security by increased farm production in the region (Khan *et al*., 2006).

Push-Pull is a novel tool for integrated pest management programs. It uses a combination of behavior modifying stimuli to manipulate the distribution and abundance of insect pests and/or natural enemies. In this strategy, pests are repelled away from the main crop (push) by using stimuli that mask the host apparency or are repellant or deterred. The pests are simultaneously attracted (pull), using highly attractive stimuli, to other areas such as refugia/traps/trap crops where they are concentrated, facilitating their control (Miller, 2009).

2.18 Components of the push – pull strategy.

The function of push components is to make the protected resource hard to locate, unattractive or unsuitable to the pest. This achieved through the use of stimuli that affect negatively influence the host acceptance (feeding and reproduction) (Swinnen *et al.,* 2012). These stimuli may act over the long or short range and ultimately lead to pest being repelled or deterred from the resource or not even approaching it. Long range stimuli represent the first line of defense: preventing or reducing infestation in the first place. Stimuli may act over a short range but, however, can be powerful tools in preventing specific pestiferous behaviours (Khan *et al*., 2013). In pull components of push – pull strategies, attractive stimuli are used to divert pests from the protected resource to refugia. The stimuli used to achieve this act mostly over a long distance. However, short – range stimuli can be useful in additions to arrest and retain the pests in a predetermined place to facilitate the concentration of their populations to prevent them from returning to the protected resource (Kfir *et al*., 2002).

These stimuli have been grouped according to whether they are visual or chemical cues, whether they are synthetic or plant – derived semiochemicals, and whether they are usually used to affect host recognition and selection over a relatively long range as visual cues, synthetic repellents, non-host volatiles, alarm, host volatiles, antiaggregations and pheromones (Khan *et al.,*2013).

CHAPTER THREE
MATERIALS AND METHODS.

3.1 Study site

This study was conducted in Trans-Nzoia County, situated at latitude 1°01' N, longitude 35°7.5'E, at an elevation of 1,890 masl. It receives on average 1,143 mm annual rainfall and the soils are loamy. The County is a continuation of the fertile Uasin Gishu Plateau beyond ("trans") the Nzoia River. The rainfall is bimodal occurring in two seasons. March to June/July and the second rain starts indistinctly around July to November. The rainfall peaks are at the end of April and end of July/August. The temperatures are relatively low due to high altitude and presence of Mt. Elgon and Cherang'ani hills with average daily temperature of 22.5± 2 ^{0}C (Mulaa *et al*.,2011).

3.2 Experimental design and layout.

The field under which studies were conducted was provided by Kenya Agricultural Research Institute (KARI) administration and farmers in the County. A completely randomized block design with three replications of five treatments was used. Each plot measuring 6x6 m with avenues of about 0.5 m between plots were maintained to ensure accessibility and facilitate daily operations during the duration of the experiment of March to November, 2011

The study applied a both the experimental and field survey methods to investigate the relative abundance and within distribution of stem borers in *Z. mays* L. and sorghum, *S. bicolor*, Sudan grass, Napier grass, and giant Setaria grass. The plots were planted at the beginning of the rains with commercial cultivar of hybrid maize H622 from Kenya Seed Company Ltd, local sorghum 9 red, Sudan grass, Napier grass Kakamega 1, KI and giant Setaria were obtain from KARI. Data was accumulated from the five treatments listed under various experiments as below:

3.2.1 Pure stands

These consisted of: Three plots of 6x6 m of maize with inter-row spacing of 75cm and inter-plant 30cm, three plots of 6x6 m of sorghum drilled with an inter-row spacing of 45cm and thinned to 15 cm intra-row spacing, three plots of 6x6 m of Sudan grass drilled with an inter-row spacing of 45 cm and thinned to 15 cm intra-row spacing, three plots of 6x6 m of Napier grass KI with inter-row spacing of 60 cm and inter-plant 60 cm and three plots of 6x6 m of giant Setaria with inter-row spacing of 60 cm and inter-plant of 60cm.

3.2.2 Mixed stands

These consisted of: Three plots of maize with inter – row of 75cm and inter-plant spacing of 30cm intercropped with Napier grass with inter – row 60 cm and inter- plant 60 cm spacing, three plots of maize with an inter – row of 75cm and inter – plant 30 cm intercropped with Sudan grass inter – row 45cm and thinned to 45cm inter – plant, three plots of maize with inter – of 75 cm and inter – plant of 30 cm intercropped with giant Setaria grass inter – row 60 cm and 60 cm inter – plant spacing, three plots of sorghum drilled with an inter- row spacing of 45 cm and thinned to 15 cm inter-plant intercropped with Napier grass with inter – row and inter – plant spacing of 60 cm, three plots of sorghum drilled with inter – row of 45 cm and thinned to 15 cm inter- plant spacing intercropped with Sudan grass of 45 cm and 45 cm spacing of inter- row and inter- plant spacing respectively and three plots of sorghum drilled with an inter- row spacing of 45 cm and thinned to 15cm inter-plant intercropped with giant Setaria grass of 60 cm inter- row and inter-plant spacing.

Fully established and grown phytogeographical patterns were as depicted in plates 3.1 –3.5 below: **The plates of photo - geographical depiction of cropping design.**

Plate 3.1: Experimental plot of maize showing drying of leaves due to stem borer damage. (Source: Author, 2011).

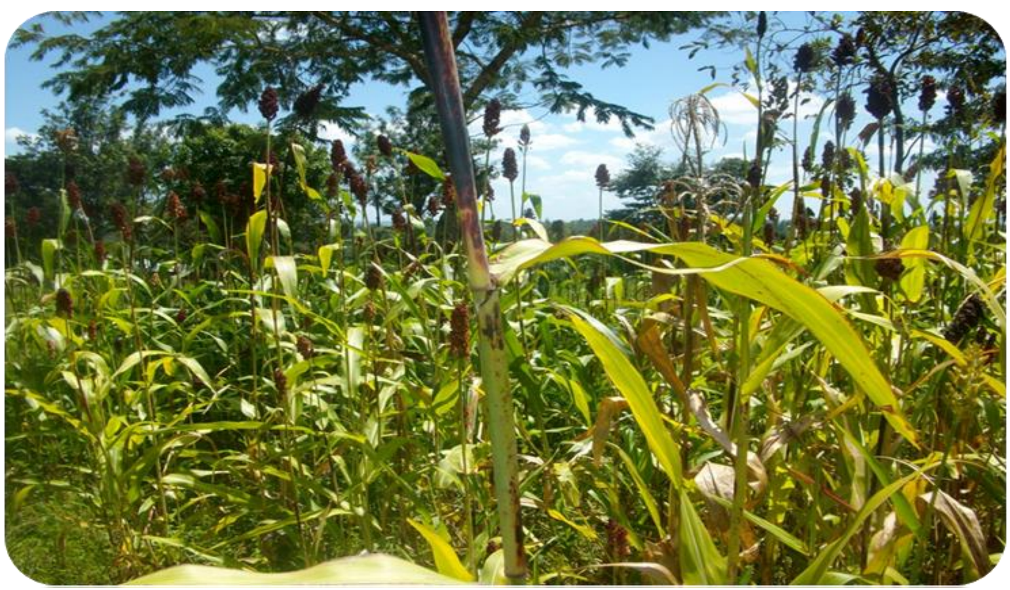

Plate 3.2: Experimental plot of matured sorghum. (Source: Author, 2011).

Plate 3.3: Experimental plot of Sudan grass at flowering stage.
(Source: Author, 2011).

Plate 3.4: Experimental plot of luxuriant Napier grass, K1.

(Source: Author, 2011).

Plate 3.5: Experimental plot of giant Setaria grass nearing harvesting. (Source: Author, 2011).

3.3 Determination of composition, identity and the geographical distribution of the stem borer complex.

In order to determine composition, identity and geographical distribution of the stem borer complex, plants were sampled at fortnightly intervals from plots and assessed for borer infestations between 2-12 weeks after emergence (WAE) as this is the period when maize and sorghum are more vulnerable to stem borers attack. At harvesting, destructive sampling was carried out on 10 plant samples per plot. Every plant was dissected and the larvae obtained were counted and recorded. Each larval insect recovered from the plants was identified using standard stem borer distinctive features. In this regard, colour, body spotting of larvae, sizes and colour of pupae were employed. Similar procedure was adopted on samples from farmers' fields although sampling was initiated when plants were two weeks old after emergence (2WAE). Sampling in farmers fields involved marking plots of 6 x6 m in the main field and randomly sampling hosts for stem borers infestation. At harvesting, 10 plants per plot were sampled and dissected as also the insects recovered in them were identified at National Museum of Kenya [NMK] following Eberhard's protocol (2008).

However, for sorghum, Napier grass KI, giant Setaria and Sudan grass, the complexity of their attack in relation to plant phenology was determined by mainly concentrating on the experimental plots at KARI and additional samples were taken from 10 randomly pre-selected farmers 20 m apart from each of the three districts in Trans-Nzoia County.

The field survey started from the fiftieth day after emergence (DAE) and continued until the Napier, Sudan grass and giant Setaria were matured and harvested.

Ten [10] plants with exit holes and frass were randomly and destructively sampled in each plot to recover the stem borers. Representatives of the stem insects damaging sorghum, Napier, giant Seteria and Sudan grass were preserved and reared in the laboratory to adult stage. The larval moths in this experiment were fed on the artificial diets that were prepared as following Cook's protocol (2007) (appendix 1).

3.4 Quantification of the relative abundance and within host distribution of stem borers in strip intercrops of gramineous crop and forage.

Two and six weeks after planting the crops and forage gramineous hosts 20 stems borer pupae (Plate 3.8 and 3.9), kept on moist filter paper, and were placed in each push-pull plot so that the emerging moths would lay eggs on the seedlings. At physiological maturity (Plate 3.10), 10 plants were randomly and destructively sampled per plot. The larvae were recovered from the hosts identified as described in 3.3, counted and recorded.

3.5 Evaluation of the effect of host plants on stem borer survival, larval development and fecundity on plants.

Three hosts from each of the 5 gramineous plants described in 3.2 were tested for stem borer preference both in the field and laboratory. Insect bioassays were conducted to measure larval development rates and fecundity of the three stem borer species (*B. fusca*, *C. partellus* and *S. calamistis*). Fifteen treatments were arranged in randomized complete block design with three replicates. Fresh stem cuttings of approximately 0.5 kg of each host plant was placed into a clean plastic jar and 10 neonate larvae from KARI – Katumani stem borer rearing facility were released in each jar (Plate 3.6), under ambient laboratory conditions (22 – 23^{o}C and 65 – 70 RH).The cuttings were replaced every week, the jars cleaned and the larval weight recorded. Days required for neonate larvae to reach pupation were recorded. At emergence, adult moths emerging from each assay were collected and transferred to a separate jar with paper wax to facilitate oviposition. The number of eggs laid was recorded daily until the moths died. The same procedure was repeated but using the artificial diet prepared as per the Cook's protocol, (2007).

3.5.1 Larva rearing

The wide collection of larvae of three species from both KARI nad farmers fields were surface sterilized following methods earlier described by Songa *et al*.,2000 and then introduced to the artificial diet in 250ml plastic jar. They were then taken to the rearing units and then reared in isolation at 28°C with a photoperiod of 12 hours light and 12 hours darkness (L:D 12:12) for *C partellus* and *S. calamistis* and 20°C for *B. fusca* until pupation and adult emergence. Extra diet was required for the last two species because the diet expired before they could complete their development.

3.5.2 Moth rearing

The adult moths were collected from the glass jar using glass vials and then sexed. Two adult moths, male and female were introduced into rearing cages. A ball of cotton soaked in distilled water was introduced into cages as source of nourishment. Butter or grease free paper was introduced in form of paper cylinders for *B. fusca* and sheets for *C. partellus* and *S. calamists* onto which the moths laid eggs (Songa *et al*., 2000).The number of eggs was recorded.

3.4.3 Egg incubation

The eggs were incubated at 28°C with a photoperiod of 12 hours light and 12 hours darkness (L: D 12:12) for *C. partellus* and *S. calamistis* and 20°C for *B. fusca* in the insectaria as described by Songa *et al.*, 2000. until the first instars larva after which they were then transferred onto 250 ml of diet in 1000 cc wide mouthed plastic jar and reared at L: D12:12 until pupation and adult moth emergence. The duration of development stage of each species was recorded.

3.5.4 Rearing the larvae to pupae

Each jar holding 250 ml of diet was infested with 50 eggs of *C. partellus* and 25 eggs of *B. fusca* and *S. calamistis* following the methods of Songa *et al*., (2000).

The insects were transferred to fresh diet in the fresh if the original diet expired before pupation.

Stem borers were also preserved and reared on naturally prepared feeds as described by Onyango *et al*., (2000). Eggs, larvae, pupae and adults were managed as described above. After the 6^{th} instar the stem borers were identified by use of keys found in standard entomology text books.

The tentative identification was confirmed by comparing with voucher specimens held at the NMK, Nairobi.

The data obtained was transformed using the square roots (x+1) before being subjected to statistical analysis of ANOVA. The post hoc test was subsequently applied to separate means.

Plate 3.6: Stem borers larvae fed on artificial diet. (Source: Author, 2011).

3.6 Elucidation of the magnitude of damage caused by stem borers on hosts.

3.6.1 Laboratory bioassays.

Bioassays were conducted to measure damage rates of the three stem borer species namely: *C. partellus, B. fusca,* and *S. calamistis* on 5 gramineous hosts. Three treatments were arranged in randomized complete block design with three replications. These assays took place at the KARI laboratory in Kitale. Fresh stem cuttings of approximately 0.5 kg of each of the 10 host plants were placed into a 1 clean plastic jar, and 10 neonate larvae collected from the field were, starved for 12 hrs to standardize their physiological status were then released in each jar, under ambient laboratory conditions (22-23°C and 65-70 RH). The cuttings were measured by weighing machines model Cl201J and accurate to 0.05g and their masses recorded and replaced every week, the jars cleaned. Days required for neonate larvae to reach pupation were recorded. At emergence, adult moths emerging from each assay were collected and transferred to a separate jar with paper wax to facilitate oviposition. The number of eggs laid was recorded daily until their fecundities were exhausted. Data collected was analyzed by analysis of variance (ANOVA) to determine the damaging rates of different species of stem borers relative to time.

3.6.2 Field evaluation of stem borer damage to gramineous hosts.

Four weeks after seedling emergence for maize and sorghum and 6 weeks after planting the forage gramineous plants, 20 stem borer pupae, kept on moist filter paper, were placed in each plot, so that the emerging moths would lay eggs on the seedlings. At physiological maturity,10 plants were randomly sampled per plot and assessed for tunnel length/ stem borer damage Plate 3.7, plants leaf damage, number of larvae and exit and entry holes, the stem diameter and dry matter yield. The leaf damage was assessed based on a 0 – 9 scale (whereby 0 was no damage and 9 very serious damage causing dead heart) scale as indicated below:

1 – 2 = slight damage

3 – 4 = moderate damage

5 – 7 = serious damage

8 – 9 = very serious damage

*An average of less than one was considered as no damage.

Plate 3.7: Damage of *B. fusca* on sorghum. (Source: Author, 2011).

3.7 Assessment of yields and economic losses caused by stem borers to the gramineous hosts.

To assess the yields and economic losses caused to the grains by the stem borers, an analytical method was used. This involved harvesting 15 infested and 15 uninfested maize and sorghum plants growing under identical conditions but 1 km apart. The cobs and heads of maize and sorghum were harvested respectively from infested and uninfested maize and sorghum and were bagged separately. They were weighed before being manually shelled to weigh the grains. The stems were then dissected to reveal the extent of stem damage which was recorded in terms of the number of borer exit holes, extent of stem tunneling and borer population (Appendix 11 and 111).

The coefficient of harmfulness was calculated as the yield loss per plant expressed as a percentage of yield from uninfected plants. Economic losses were assessed using Maddonni *et al*., (2006) formula as represented below:

$$C = (a – b)/a$$

$$L = CP/100$$

Where:

a = mean yield of uninfected plants

b = mean yield of infested plants

C = Coefficient of harmfulness

P = % plants attacked

L =% economic loss

A simple micro – economic analysis was carried out on gathered data to depict cost – benefit ratios indicating the cost – effectiveness of using refugia gramineous plants to control stem borers and to estimate their complimentary valued attributes when incorporated in an IPM programme. The grain yields obtained were converted into kg/ha and calculated in monetary terms at the prevailing average price of K.sh 35 and K.sh 40 per kg for maize and sorghum respectively. The cost benefit analysis was carried out by calculating the (C/B) which compared the control costs with the expected benefits derived from using each forage refugia.

The C/B ratio was calculated using a modified version of Heiko (2009) as thus:

C/B = (CC +AC) NW/MV x RY

Where:

C/B = cost benefit ratio,

CC = cost of refugia (This include cost of seeds planting),

AC = cost of labour e.g. applying fertilizer, weeding the refugia etc

NW = number of times the refugia are weeded and fertilizer applied,

MV = Market value of the crop [Ksh /Kg],

RY = Realised grain yield [kg / ha].

The cost incurred included: amount of labour used for planting, weeding and harvesting. This was measured in work - days of actual work done in the field including each operation carried out. The quantities of inputs used in particular, seeds, basal and top dress input fertilizers were recorded. The yields were measured and recorded. Local input and output prices were also recorded.

The production costs and revenue each refugia option was computed and extrapolated from plot level to per hectare basis for comparison.

The C/B was interpreted as follows:

If the ratio was >1, then the biocide and its costs of management was not economically favourable as the costs outweighed the benefits, and vice – versa.

3.8 Establishment of the efficacy of using preferred refugia of stem borers in a pull-push pest management strategy.

Six weeks after planting the forage gramineous hosts 20 stems borer pupae (Plate 3.8 and 3.9), kept on moist filter paper, and were placed in each push-pull plot so that the emerging moths would lay eggs on the seedlings. At physiological maturity (Plate 3.10), 10 plants were randomly sampled per plot and assessed for tunnel length, leaf damage, number of larvae per grass species and exit and entry holes, stem diameter. This supplemented maize and sorghum that were surrounded with Napier, Sudan and giant Setaria grass as described in 3.2 (b). The intercrop with forage gramineous maize and sorghum that recorded the least damage hence lowest yield loss was regarded the appropriate refugia**.**

The eggs, larvae, pupae and adults used in this experiment were managed in jars and vials as described in appendix 1.

Plate 3.8: Pupae of *B. fusca* in a controlled laboratory. (Source: Author, 2011).

Plate 3.9: Caged pupae of *B. fusca* in a controlled laboratory
(Source: Author, 2011).

Plate 3.10: Adults moths emerging from pupae in a laboratory.
(Source: Author, 2011).

CHAPTER FOUR

RESULTS

4.1 Determination of composition, distribution and identity of stem borer species on gramineous hosts in different ecozones.

In the highlands of Trans-Nzoia County such as Mt. Elgon and Cherang'ani Hills, *B. fusca* was the only stalk borer identified that attacked maize crops at 6 weeks after emergence (WAE). By then, the maize crop was about the sixth leaf stage. However, infestation was generally low (Table 4.1). At 6 weeks after germination, approximately 4 borers/ 10 plants (0.4 ±0.2 larvae/ plant) were recorded. The population increased four-fold at 12 WAE when 15 borers/ 10 plants (1.5 ± 0.6 larvae/ plant) were recorded. Infestation lasted till harvesting when *B. fusca* borers were recorded from both maize stems and cobs. In the lower elevetions of the County, the predominant borer was the spotted stalk borer *C. partellus*. *Chilo partellus* attacked the crops from 3 WAE initially with a population of 6 borers/ 10 plants (0.6 ± 0.1 larvae/ plant). This rose phenomenally by four-fold to 22 borers/ 10 plants (2.2 ± 0.8 larvae/ plant) at 7 WAE. Two weeks after, (9 WAE), the *S. calamistis* invaded the fields and attacked maize together with *C. partellus*. However, the population of the former species was low till harvesting time.

Table 4.1: Interrelationship of stalk borer species and age of gramineous plants from two ecological zones in Trans-Nzoia County, March-November, 2011.

Highlands			Lowlands		
Plant species age	Mean borers / plant	borer species	Plant age	Mean borers/plant	borer
2 WAE	0.0	-	3 WAE	0.6 ± 0.1	*C. partellus*
4 WAE	0.0	-	5 WAE	0.4 ± 0.2	*C. partellus*
6 WAE	0.4 ± 0.2	*B.fusca*	7 WAE	2.2 ± 0.8	*C. partellus*
8 WAE	1.0 ± 0.3	*B.fusca*	9 WAE	1.5 ± 0.6	*C. partellus*
				0.6 ± 0.3	*S. calamistis*
10 WAE	0.9 ± 0.5	*B.fusca*	11 WAE	0.9 ± 0.3	*C. partellus*
				0.4 ± 0.2	*S. calamistis*

4.2 Relative abundance and within host distribution of stem borers in strip intercrops of maize, sorghum and three graminae refugia.

Busseola fusca was the most prevalent stem borer species in all the hosts with a mean of 6.4 stem borers per plant. It was followed by *C. partellus* which had a mean of 4.80 stem borers. The *S. calamistis* species was the least prevalent with a mean of 2.00 stem borers/plant (Table 4.2).

Table 4.2: Relative abundance within host distribution of stem borers in strip intercrops maize, sorghum and graminae refugia.

B. fusca	Maize	Sorghum	Grasses	Mean	Std Dev	Std error
1	8.3[ab]	7.7[ab]	6.3[ab]	6.42	3.834	1.715
2	7.4[b]	8.1[a]	5.9[b]			
3	4.3[c]	2.6[c]	5.7[c]			
4	8.1[a]	7.3[b]	4.4[c]			
5	6.1[c]	5.3[c]	6.7[a]			
C. partellus						
1	10.2[ab]	4.6[c]	0.9[c]	4.80	3.271	1.463
2	3.4[c]	8.7[a]	2.7[ab]			
3	5.6[c]	2.3[c]	1.8[b]			
4	6.1[b]	5.6[ab]	1.6[c]			
5	10.7[a]	4.8[b]	5.0[a]			
S.calamistis						
1	3.3[b]	2.3[ab]	1.5[ab]	2.00	2.000	.894
2	2.6[c]	3.1[a]	0.7[c]			
3	3.7[ab]	0.6[c]	1.8[a]			
4	0.3[C]	0.7[b]	0.4[c]			
5	5.1[a]	2.3[ab]	0.6[c]			

4.3 Evaluation of the host plants on stem borer survival, larval development and fecundity on host plants.

The laboratory studies revealed that there were significant differences in life cycle, % survival and number of eggs laid ($p < 0.05$) on the crop host plants and graminae refugia hosts by *B. fusca*, *C. partellus* and *S. calamistis*. Larvae reared on maize and sorghum had the shortest development period [life cycle] of 53.2 and 55.4 days respectively with those reared on giant Setaria showing the longest development period of 65.4 days (Table 4.3).Durations in Napier and Sudan grasses were 60.2 and 63.4 days respectively.

Egg production per female was highest for larvae reared on maize and lowest for giant Setaria. Percentage survival was significantly ($p < 0.05$) highest on maize with 37.8%, followed by sorghum with 32.8% while Napier, Sudan and giant Setaria grasses provided nearly equal effects in borer survival which were 11.5%, 11.2% and 6.7% respectively.

The larval weight gain was generally greatest for the two preferred hosts, maize and sorghum for the prevalent species of stem borer: *B. fusca* and *C. partellus* (Table 4.4).The trend followed the same analogy as for survival.

The type of diet had a significant ($p < 0.05$) effect on the development of the stem borers: longevity of the life cycle, percentage survival and the number of eggs produced. More eggs were produced when these stem borers were fed on artificial feeds than on natural feeds with means of 90.4 and 53.7 respectively (Table 4.5).

Table 4.3: Life cycle, egg production and survival *B. fusca* and *C. partellus* reared on gramineous hosts

Host plant	Lifecycle (Days)	Survival (%)	No. of egg produced	Life Cycle (days)	Survival (%)	No. of eggs produced
Maize	53.2[c]	37.8[a]	215.0[a]	55.9[c]	25.3[ab]	93.0[a]
Sorghum	55.4[c]	32.8[ab]	184.8[ab]	56.5[c]	13.3[c]	67.0[ab]
Napier grass	60.2[ab]	11.5[b]	146.6[b]	60.7[ab]	27.5[a]	62.3[b]
Sudan grass	63.4[b]	11.2[b]	140.2[c]	65.3[b]	18.4[b]	60.1[b]
Giant Setaria	65.4[a]	6.7[c]	135.4[c]	67.5[a]	15.7[c]	55.7[c]

Means with the letter in a column are not significantly different from each other at $p < 0.05$.

Table 4.4: Average larval weight of three species of stem borer on gramineous hosts.

Host plant	*C. partellus*	*B. fusca*	*S. calamistis*
Maize	0.035[a]	0.038[a]	0.018[b]
Napier grass	0.023[ab]	0.025[b]	0.020[ab]
Sorghum	0.017[c]	0.026[ab]	0.014[c]
Sudan grass	0.024[b]	0.025[b]	0.021[ab]
Giant Setaria	0.025[b]	0.012[c]	0.025[a]
Overall mean	0.0245	0.0252	0.0196

B.fusca	C.partellus

Table 4.5: Effect of the type of diet on fecundity of stem borers.

T-test

Host	Artificial diet	Natural diet
1	90.1[b]	53.3[a]
2	85.5[c]	50.7[b]
3	92.9[ab]	42.3[c]
4	94.1[a]	48.1[b]
5	90.1[b]	51.3[ab]
Mean	90.4	53.7
Std Dev.	1.63941	2.21084
Std error	.527220	.284700

4.4 Elucidation of the magnitude of damage caused to maize, sorghum and potential refugia by the stem borers.

4.4.1 Bioassay in the laboratory

The magnitude of damage to the gramineous hosts varied subject to nature of the graminae. *Busseola fusca* was the most devastating stem borer to maize, sorghum, Napier and Sudan grass with a mean of 6.5, 6.0, 5.6 and 5.3 per plant respectively. *S.calamistis* was the least devastating in the same hosts with means of 2.5, 2.2, 2.7 and 3.2 per plant respectively. *Chilo partellus* was the most devastating to giant Setaria grass with a mean of 5.1 and *B.fusca* being the least devastating with a mean of 3.5 per the giant Setaria grass (Table 4.6 – 4.10).

Table 4.6: Damage of stem borers to maize in the laboratory.

Hosts	*B.fusca*	*C.partellus*	*S. calamistis*	Total
1	7.2[ab]	4.8[b]	2.2[b]	
2	7.6[a]	5.6[ab]	3.1[ab]	
3	6.3[c]	5.3[ab]	2.1[c]	
4	7.5[a]	3.7[c]	3.4[a]	
5	3.9[c]	6.4[a]	1.5[c]	
Mean	6.5000	5.1667	2.4667	4.7111
Std. Dev	.50000	1.10604	2.04042	2.13918
Std .Error	.28868	.63857	1.17804	.71306

Table 4.7: Damage of stem borers to sorghum in the laboratory.

Hosts	*B.fusca*	*C.partellus*	*S.calamistis*	Total
1	6.7[ab]	4.8[b]	3.2[b]	
2	5.2[c]	6.7[a]	1.8[c]	
3	7.1[a]	5.3[ab]	1.7[c]	
4	5.8[b]	3.9[c]	3.6[ab]	
5	5.2[c]	3.3[c]	0.9[c]	
Mean	6.0000	4.8000	2.2333	4.3444
Std. Dev	1.0000	1.21244	1.30512	1.95455
Std .Error	.57735	.70000	.75351	.65152

Table 4.8: Damage of stem borers to Napier grass in the laboratory.

Hosts	*B.fusca*	*C.partellus*	*S.Calamistis*	Total
1	5.2[b]	4.8[ab]	1.9[c]	
2	6.7[a]	6.9[a]	2.1[b]	
3	4.9[c]	6.9[a]	2.3[b]	
4	5.3[b]	3.8[b]	1.7[c]	
5	5.1[b]	2.1[c]	3.3[a]	
Mean	5.6000	4.3667	2.667	4.0778
Std. Dev	.80000	1.11505	1.42244	1.76265
Std .Error	.46188	.64377	.82125	.58755

Table 4.9: Damage of stem borers to Sudan grass in the laboratory.

Hosts	*C.partellus*	*B.fusca*	*S.calamistis*	Total
1	3.8[b]	6.3[ab]	5.2[a]	
2	5.7[a]	7.1[a]	1.9[c]	
3	4.3[c]	4.3[c]	3.3[b]	
4	3.9[b]	5.6[b]	4.3[ab]	
5	4.8[c]	4.9[c]	1.3[c]	
Mean	4.5000	5.6333	3.2000	4.4444
Std. Dev	1.50997	.64291	.36056	1.34825
Std .Error	.87178	.37118	.20817	.44942

Table 4.10: Damage of stem borers to giant Setaria grass in the laboratory.

Hosts	*B.fusca*	*C.partellus*	*S. calamistis*	Total
1	3.8[ab]	7.2[a]	3.8[ab]	
2	4.9[a]	3.6[c]	5.2[a]	
3	3.4[b]	3.2[c]	1.7[c]	
4	2.6[c]	4.7[b]	2.4[b]	
5	3.0[c]	6.8[ab]	3.6[ab]	
Mean	3.5333	5.1000	3.3333	3.9889
Std. Dev	.81445	.43589	.51316	.99051
Std .Error	.47022	.25166	.29627	.33017

4.4.2 Field assessment of stem borers damage to the gramineous hosts

The magnitude of damage of the stem borers caused on hosts was significant ($p < 0.05$). *Busseola fusca* was the most devastating stem borer in maize, sorghum, Napier grass and Sudan grass with means of 4.9, 3.9, 2.2 and 1.4 tunnel length/host respectively (Tables 4.11 – 4.14). However, it had the least damaging in giant Setaria grass with a mean of 0.7 tunnel length/ host. *Chilo partellus* was the most devastating stem borer on giant Setaria grass with mean of 3.300 tunnel length/plant (Table 4.15). However, S. *calamistis* was the least devastating species in maize, sorghum, Napier and Sudan grass with a mean of 1.1, 0.9, 0.5 and 0.6 tunnel length/ host respectively. These damages included: destruction of the maize grains (Plate 4.1), formation of exit and entry holes (Plate 4.2), “windowing” of leaves (Plate 4.3) and damaging of the tassels (Plate 4.4).

There was a significant positive correlation (r = .059**) between the number of stem borer larvae recovered from damaged stems and exit and entry holes (Table 4.16). Many exit entry holes implies many stem borers entered the stem giving rise to more larvae. The number of larvae recovered had a positive correlation (r = .074**) to the leaves' damage caused (Table 4.17). Also, the stem diameter positively correlated (r = .062) with the number of larvae recovered (Table 4.18).

There were significant differences among the refugia crops and forages ($p < 0.05$) in all traits measured. Results from the field trials indicated higher stem borer damage rating and exit holes in maize and sorghum than in gramineous forages. The highly damaged hosts were maize, sorghum and Napier. However, it was notable that gramineous crops had the highest leaf damage scores although; Napier grass, Sudan grass and giant Setaria grass also showed some leaf damage scores. The highest numbers of larvae recovered per plant were from maize, sorghum and Napier grass and least in giant Setaria grass (Table 4.19).

Table 4.11: Tunneling effect of stem borers to maize in the field.

Hosts	*B.fusca*	*C.partellus*	*S. calamistis*	Total
1	6.3[ab]	4.6[a]	0.9[c]	
2	7.4[a]	3.1[ab]	1.2[b]	
3	2.3[c]	2.9[b]	1.4[a]	
4	3.7[C]	4.6[a]	1.3[ab]	
5	4.7[b]	11.3[c]	0.5[c]	
Mean	4.8800	3.3000	1.0600	1.8133
Std. Dev	1.18659	1.63187	.80808	1.28667
Std .Error	.53066	.72979	.36139	.33222

Table 4.12: Tunneling effect of stem borers to sorghum in the field.

Hosts	*B.fusca*	*C.partellus*	*S.calamistis*	Total
1	4.3^{b}	3.3^{a}	0.9^{ab}	
2	5.1^{ab}	3.1^{ab}	1.3^{a}	
3	2.3^{c}	2.4^{c}	0.7^{c}	
4	2.5^{C}	3.2^{b}	0.9^{ab}	
5	5.5^{a}	2.7^{c}	0.8^{b}	
Mean	3.8800	2.9400	.9200	3.0333
Std. Dev	4.72356	3.56861	.76616	3.60826
Std .Error	2.11244	1.59593	.34264	.93165

Table 4.13: Tunneling effect of stem borers to Napier in the field.

Hosts	*B.fusca*	*C.partellus*	*S.calamistis*	*Total*
1	3.1^{ab}	2.5^{b}	0.5^{ab}	
2	2.9^{b}	2.7^{ab}	0.7^{a}	
3	0.7^{c}	0.9^{c}	0.4^{c}	
4	3.2^{a}	3.1^{a}	0.2^{c}	
5	1.3^{c}	1.5^{c}	0.5^{ab}	
Mean	2.2400	2.1400	.4600	2.4267
Std. Dev	3.74192	3.17222	.42190	3.0260
Std .Error	1.67344	1.41866	.18868	.7813

Table 4.14: Tunneling effect of stem borers to Sudan grass in the field.

Hosts	*B.fusca*	*C.partellus*	*S.calamistis*	Total
1	0.9^{b}	0.3^{c}	1.2^{a}	
2	1.3^{ab}	1.1^{a}	0.7^{ab}	
3	0.7^{c}	1.1^{a}	0.6^{b}	
4	2.3^{a}	0.4^{b}	0.3^{c}	
5	1.8^{b}	1.0^{ab}	0.3^{c}	
Mean	1.4000	0.7800	0.6100	2.5333
Std. Dev	.72595	6.04541	1.25100	3.9462
Std .Error	.32465	2.70359	.55946	1.0189

Table 4.15: Tunneling of stem borers to giant Setaria grass in the field.

Hosts	***B.fusca***	***C.partellus***	***S .calamistis***	**Total**
1	0.7[ab]	3.5[b]	2.2[a]	
2	0.6[b]	3.7[ab]	2.1[ab]	
3	0.3[c]	2.3[c]	1.3[b]	
4	1.4[a]	2.7[c]	1.5[b]	
5	0.4[c]	4.5[a]	0.9[c]	
Mean	0.6800	3.3000	.1.6000	1.8600
Std. Dev	.63797	2.6488	1.28841	1.9741
Std .Error	.28531	1.19624	.57619	.5097

Table 4.16: The correlation entry and exit holes with the occurrence of larvae

		Entry and exit holes	Number of larvae
Entry and Exit holes	Pearson correlation		
	Sig.(2 tailed)	1.000.	.059**
	N	250	.001
			250
Number of larvae	Pearson Correlation		
	Sig.(2 tailed)	.059**	1.000
	N	.001	.
		250	250

*Correlation is significant at the 0.05 level (2 tailed).

Table 4.17: The correlation of prevalence of number of larvae to leaf damage

		Number of larvae	Leaves damage
Number of larvae	Pearson Correlation	1.000	.074**
	Sig. (2 tailed)	.	.001
	N	250	250
Leaves damage	Pearson Correlation	.074	1.000
	Sig.(2 tailed)	.001	.
	N	250	250

*Correlation is significant at the 0.05 level (2 tailed).

Table 4.18: The correlation of stem diameter and larvae abundance.

		Stem diameter	Number of larvae
Stem diameter	Pearson Correlation	1.000	.062**
	Sig. (2 tailed)	.	.001
	N	250	250
Number of larvae	Pearson Correlation	.062**	1.000
	Sig.(2 tailed)	.001	.
	N	250	250

** Correlation was significant at the 0.05 level (2 tailed).

Table 4.19: Plant traits measured after infesting graminae species with stem borers.

Entry	Host Plant	No. Of stems damaged	Stem Borer exit holes	Leaf damage score(1-5)	Larvae per plant (No.)	Stem diameter (cm)	Dry matter yield (t/ha)
1	G.grass	5.43^{c}	0.52^{c}	0.77^{c}	0.01^{c}	0.55^{c}	0.89^{c}
2	S.grass	8.72^{c}	0.56^{c}	1.03^{c}	0.06^{c}	1.02^{b}	1.67^{b}
3	Sorghum	13.27^{b}	1.36^{ab}	1.36^{ab}	0.11^{ab}	1.25^{ab}	1.82^{ab}
4	Maize	14.84^{a}	2.34^{a}	2.61^{a}	0.16^{a}	2.27^{a}	3.26^{a}
5	N. grass	12.58^{ab}	1.08^{b}	1.32^{b}	0.09^{b}	1.19^{ab}	1.9^{ab}

Means with the same letter in a column are not significantly different from each other at $p < 0.05$

Key:

G = Giant Setaria, S =Sudan, N = Napier

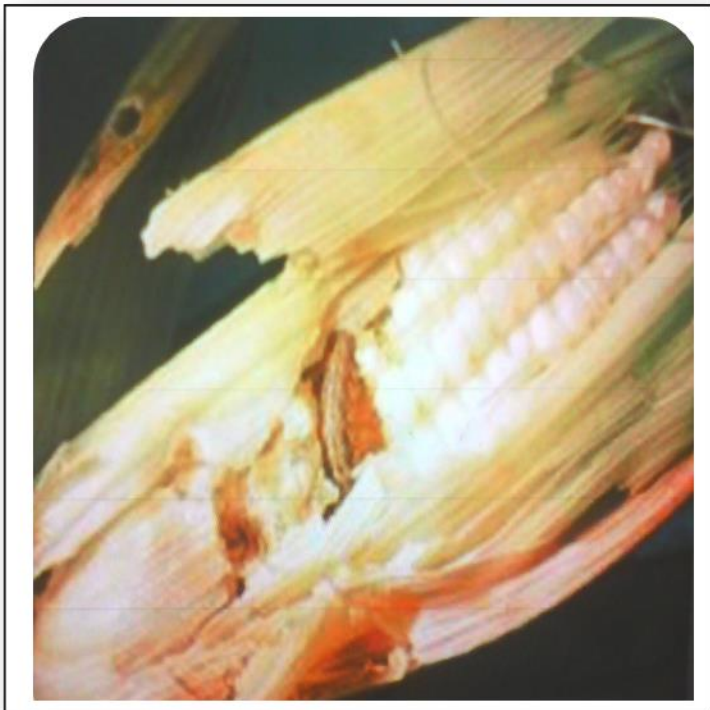

Plate 4.1: Damaged maize grains by *C. partellus*. (Source: Author, 2011).

Plate 4.2: *Busseola fusca* tunneling a maize cob. (Source: Author, 2011).

Plate 4.3: Exit and entry holes caused by *S. calamistis* to maize stem. (Source: Author, 2011).

Plate 4.4: Windowing effect of *B. fusca* to maize leaves. (Source: Author, 2011).

Plate 21

4.5 A ... ds and economi...

The Table 4.20 Shows various yields of the grains maize and sorghum realized after intercropping them with the forage refugia used in study. The lowest average was obtained in maize and sorghum protected by giant Setaria grass. This was 106.6g/plant and 114g/plant respectively.

The table shows that the average grain realized from the biologically protected plots with gramineous refugia were significantly ($F = 46^*$; $p < 0.05$) different from the control experimental plots. The average grain loss in protected maize and sorghum plots was 4.9% and 7.1% respectively.

The grain yield loss due to the stem borers in unprotected maize and sorghum as shown in the table 4.20 was 22.9% and 10.9% respectively. The protection of gramineous refugia to the grain crops was significant ($p < 0.05$).The maize yield reductions were 2.02%, 5.1% and 7.65% were realized when the maize crop was protected by Napier grass, Sudan grass and giant Setaria grass respectively.

The sorghum had grain loss of 5.8%, 6.5% and 9.1% when protected with Napier, Sudan grass and giant Setaria grass respectively.

The type of the gramineous refugia had a significant ($p < 0.05$) effect of stem borer management on the cereal crop protected. The Napier grass was the most effective graminea refugia. It reduced grain yield loss to 2.02% in maize and 5.8 % in sorghum.

The giant Setaria grass was the least effective gramineous refugia. It reduced grain loss to 7.7 % and 9.1% maize and sorghum respectively.

Table 4.20: Effects of push –pull strip intercrop management strategy on grain yield loss

Treatment	Mean grain Weight / plant [g]		Grain Yield Loss[%]
Maize	106.6[c]		22.94
Sorghum	_	123.5[c]	10.92
Maize xNapier grass	135.8[a]	_	2.02
Maize xSudan grass	131.9[ab]	_	5.10
4**Maize xG.Setaria grass**	128.0[b]	_	7.65
. **Sorghum xNapier grass**	_	130.6[a]	5.77
6**Sorghum xSudan grass**	_	129.5[ab]	6.51
Sorghum xSetaria grass	_	126.5[b]	9.1
F- value	46.29*		
CV	7.8		

4.6 The efficacy of the most preferred gramineous refugia of stem borers in a push and pull management strategy.

4.6.1 Laboratory evaluation of the forage gramineous refugia.

There were significant differences ($p < 0.05$) among the forage refugia with regard to life cycle, percentage survival, and number of eggs produced by the devastating stem borers: *B.fusca* and *C. partellus*. The life cycles of the larvae *B. fusca* and *C. partellus* were shortest when reared on Napier grass with means of 60.2 and 60.7 days. They were longest when reared on giant Setaria with means of 65.4 and 67.5 days (Table 4.3). This showed the longest development time on giant Setaria.

Egg production per female was highest for larvae reared on Napier grass and lowest for giant Setaria with means of 146.6 and 135.4 eggs for *B. fusca* species, 60.1 and 55.7 eggs for *C. partellus*. The *B. fusca* species for management is a major concern, showed the highest survivorship on Napier grass with 11.5% followed by Sudan grass with 11.2% and lowest on giant Setaria with 6.7%. The larval weight gain was generally greatest for the two preferred forage refugia hosts: Napier grass and Sudan grass for *B. fusca* had 25% while *C. partellus* had 23% and 20% respectively (Table 4.4). This implied Napier grass has a greater ability to habour stem borers especially the most devastating *B. fusca* a principle ingredient in the pull and push management strategy.

Napier grass was the most preferred refugia for *B.fusca* whose tunnel length mean was 5.6 per plant followed by Sudan grass with a mean of 4.5 per plant. However, giant Setaria was the least preferred host of *B. fusca* with a tunnel length mean of 3.5 per plant. Giant Setaria was the most preferred refugia for *C. partellus* with a tunnel length mean of 5.1 per plant and least attractive to *B. fusca* whose damage mean was 3.5per plant.

4.6.1 Field evaluation of the forage gramineous refugia.

There was a significant difference among the forage refugia ($p < 0.05$) in all traits measured (Table 4.20).The most damaged plant was in Napier grass followed by Sudan grass and least in giant Setaria grass with means of 12.6, 8.7 and 5.4 respectively. This was the same with regard to the number of stem borer exit holes, leaf damage and the number of the larvae recovered from the dissected forage gramineous refugia.

Also, yield reduction was highest in maize intercropped with Napier grass and sorghum intercropped with Napier grass at 2.0% and 5.8% respectively. Least yield reduction was recorded in the mixed stands of maize, giant Setaria and sorghum, giant Setaria at 7.7% and 9.1% (Table 4.20).

CHAPTER FIVE.

DISCUSSION

The studies established the relative abundance and quantified the pest populations. The stem borers that can be controlled by growing different potential refugia graminae in mixtures with maize and sorghum in any of the zones diferred. *B. fusca* and *C. partellus* were the stem borer species identified in maize, sorghum, Napier grass, Sudan grass and giant Setaria in highland and the lowland regions of the county respectively. In the latter site, a near negligible incidence of *S. calamistis* was recorded .The two borer species were more prevalent than the latter and showed distinct agro-ecological zone preference. This has been the observed trend since the last two decades (De Grote, 2002). The altitude seemed to have led to the apparent observed distribution, with *B. fusca* preferring the highland areas and *C. partellus* occurring in the lowland areas. Their relative stability in the areas of occurrence of those species was due to the altitudinal adaptations and affinities which lacked in the *C.partellus* species which had not upsurged into their endemic areas (Mulaa *et al*., 2011). The stability in the pest status could have also been due to lack of changes in agronomic practices effected over the period to either enhance or empede the species spread as changes in cultural practices over long durations may ultimately alter pest status (Charcosset & Horst,2005).

Species diversity had not drastically altered meaning that continuous growing of maize and sorghum in juriposition with Napier, Sudan and giant Setaria grasses has led to highly variable regimes of survival and development of stem borers (Mulaa *et al*.,2011).

The magnitude of damage of the stem borers to the gramineous host depended on the volatile compounds they probably emitted although they were not determined perse in these studies. The *Zea mays* L. emits the following volatile compounds identified by coupled gas chromatography – electro - antennographic detector (GC – EAD analysis): copaene, (Z)-3-hexenol, (E)-2- hexenol,3-hexenyl acetate , (Z) -3-hexenyl acetate, linalool, 4.8 – dimethyl – 1,3,7 – nonatriene,indole,a – *trans* – bergamotene,(E) – b –farnesene, (E) – nerolidol, (3E,7E) –4,8,12 – trimethyl – 1,3,7,11 – tridecatetraene (Khan et *al*.,2013), while the *S.bicolor* L. emits the following volatile compounds: tuolene,hexenol, (Z) – 3-hexenol, M – xylene, O –xylene (Z) – 3 – hexenol acetate, nonanal and decanal this attracts more stem borers inflicting higher magnitudes of damage (Miller,2009).

However, the refugia gramineous hosts : *P. purpureum* Schumach, Sudan grass and giant Setaria grass emit the following volatile compounds identified using Reverse phase/porapak and gas chromatography mass spectrometer (GC – MS) technique (Khan &Khan, 2006). This was confirmed by GC – co – injections (Mugo *et al*., 2005).Octanal,decanol,octadecanol,*trans*–Caryophyllene,B–fernesene,(a+B) Humulene,tridecanol, 1 – Pentacontal,cedrol, 2 – hexyldecanol, 3,7,11 – Trimethyl-2,6,10 – dodecatrienol and *bis* (2- methoxyethyl) phthalate. It was possible that what was observed resulted from a conglomerate of complex air borne volatiles interacting and acting on borers thus attraction of volatiles to hosts increased to damages caused by stem borers to hosts Kok and Kok, 2001).

Of these volatile compounds, those emitted by *Z. mays* L. were more attractive to *B. fusca* than they are to the *C.partellus* and *S. calamistis* as they have more electro -physiologically and behaviourally active compounds (Amudavi *et al*., 2009).Volatiles from *Sorghum bicolor* were relatively attractive to *B. fusca* than to *C.partellus* and *S. calamistis* in comparison to the emissions from refugia gramineous hosts as they have less electro - physiologically active compounds (Mulaa *et al*., 2011).This specifity suggests that the gramineous plants provides crucial cues for infestation by the stem borers. The cues lead to a greater propensity for searching maize perhaps spacing recommended for growing crops most appropriately facilitate an amenable pattern that confers protective properties to stem borers. More importantly, the preference of the *B.fusca* to *Z. mays* L. majorly is a reflection of the genetic adaptation to searching maize (KARI, 2012).Therefore, the emission of attractants to *B. fusca* by *Z. mays* L. resulted as it inflicted more injury to maize and other gramineous plants which in the descending order could be based on the type of volatiles released. Decreased attack was aligned to appropriate chemical emitted. Also, the *B. fusca* feeds more veraciously accounting for a larger magnitude of damage comparative to the other stem borers in this study.

The morphological traits of the Zea *mays* L. led to its increased infestation by the *B.fusca* causing more overall damage such as its stem diameter and reduced trichomes which are known physical isolating mechanisms (Maddoni *et al*., 2006).

The great magnitude of damage to maize could have been due to the biochemical factors. It has more of amino acids, sugars, than the other gramineous hosts (Souza, 2002).These probably provided adequate respiratory substrates providing energy for the physiological processes of stem bores such as growth, development and reproduction. This led to the larvae reared on maize and sorghum possessing short life cycles 53 – 55 days, a highest survival percentage of 32 – 37 compared to 60 – 65 and 6.7 and 11.5% in grasses and egg production per female being the highest among other hosts. This also translated to increased population growth rate to reach the economic injury levels a feat Gethi *et al.*, (2001) envisaged over 15 years.

Sorghum bicolor L. had a lower damage in comparison to maize due to probably antixenosis hence its sap had a negatively affected the fecundity of the stem borers. Therefore, survival of *B. fusca* in maize and sorghum compared to the three graminae hosts was 3.3 – 3.4, 2.8 – 2.9, and 5.6 – 4.9 times more than in Napier ,Sudan grass and giant Setaria grass respectively. Consequently, survival appeared to be the main panacea that elucidated antixenosis since it forms a fundamental component for assessing the ability of the plant to deter attacks on them. It has co – existed with the stem borers for a relatively longer period leading to co – evolution resisting stem borer damages such as possessing more trichomes and the epicuticular wax layer which conspicuous and hampers climbing of the stem borers (Tollenaar *et al*., 2006). Antibiosis leads to high mortality in the early larval stages, low larval establishment, time interval between larval hatching and boring into the stem, larval mass and the survival rate (Nyamangara *et al*., 2013).

Resistance in the current studies was only physical and probably mechanically determined through weighings and countings. On the contrary, the volatiles from the gramineous forages were more attractive to the *B. fusca* and *C. partellus* than to the *S. calamistis* as they are more electro - physiologically and behaviourally active compounds to the former stem borers than the later (Tabashnik *et al*., 2003).This led to more damage caused to the *P. purpureum* Schumach, Sudan grass and giant Setaria grass by *C. partellus* and *S. calamistis* than *B. fusca.*

High altitudes favours synthesis of volatiles that evoke positive taxes to *B. fusca* towards the gramineous hosts than the lower altitudes (Khan *et al.,* 2013).This leads to increased abundance of *B. fusca* in the former altitudes than in the later altitudinal regions (Wengui, 2003).

However, the forage gramineous refugia were less devastated by the stem borers compared to the gramineous food crops due to the biochemical factors such as acid detergent fibers, high lignin content,phenols,silica contents etc (Onyango *et al*.,2000). They cause non – preference to the stem borers to enter into the stems of these hosts. Also these have numerous trichomes on the leaves offering non – preference for oviposition curtailing the population from raising to the economic threshold nor economic injury level (Tollenaar *et al*., 2006).The Napier and Sudan grass secret a gummy substance that traps moths and prevents over 80% of the stem borer larvae from reaching the adulthood reducing their population growth (Granados, 2000).The average damage of stem borers to the Napier and Sudan grass superceded that to the giant Setaria due to physical isolation caused by their stem diameter since its stem was thinnest thus stem borers could not to grow to large enough to pupate in the host (CAB, 2002).The surface conformation of the studied plants had varied leaf smoothness and glossiness, the attributes that enabled their physical deterrence of stem borer attack to be aligned to these properties (Kok and Kok,2001).

The artificial feeds increased the growth and development of stem borers in terms of egg production. The larvae fed on artificial feeds had mean eggs production of 90.4 compared to those fed on natural feeds that had a mean of 53.7 due to the balanced proportions of nutrients in the artificial feeds as opposed to the latter. This phenomenon has been observed since 2005 (Chabi – Olaye *et al*., 2005).

The site where the experiments were conducted had a significant effect on the infestation and magnitude of devastation caused by stem borers to the gramineous refugia ($p < 0.05$). This was due to greater degree of devastation in the laboratory than in the as a result of controlled ecological conditions at optimum levels such as ambient laboratory conditions of 22- 23^{o}C and relative humidity (RH) of 65 –

70.This is contrary to the field ecological conditions which invariably differ. This causes a stress to the physiology of the stem borers (Mugo *et al*., 2004; KARI, 2012).

The number of exit and entry of the stem borers on the stems of the gramineous plants was positively (r = 0.059**) correlated with the number of larvae recovered from the dissected stems as the later was also positively (r = 0.074**) correlated with the damage caused on the leaves by the stem borers. This is because more exit and entry holes showed that more stem borers entered into stem, laid eggs which hatched to larvae that cause severe damages to the hosts' morphological parts such as stems and leaves in other crops (De Groote, 2007). Also the stem diameter had a positive (r = 0.062**) correlation with the abundance of the larvae in the stems due to the physical isolation principle which has been known for over 10 years (Pingali, 2001).

The Napier grass K1 showed a greater potency of control stem borers both in maize and sorghum. Although it emits related chemical volatiles to those emitted by Sudan grass and giant Setaria grass, Napier grass has a higher concentration of these volatiles with lower olecular weights hence their dispersion rates is more attracting even distant stem borers to it (James, 2004;KARI, 2011).

CHAPTER SIX

CONCLUSIONS

The execution of the present studies facilitated the following inferences:

i. The study showed that three stem borers exist Trans-Nzioa County. These were *B. fusca,* C. *partellus* and *S. calamistis*. *Busseola fusca* predominantly occupied highlands while C. *partellus* species occupied mainly the lowlands. However, the occurrence of *S. calamistis* is in lowlands and is scanty.

ii. The *B. fusca* was the most abundant species in within host distribution of stem borer in cereal and forage graminae intercrops while *S. calamistis* was the least abundant.

iii. The *B.fusca* was the most devastating stem borer species and it preferred hosts with larger stems thus its control is therefore of paramount importance.

iv. The Napier grass was the most effective forage gramineous refugia. When intercropped with maize it reduced stem borer damage to as low as 2.0% and 5.8% damage in sorghum. Therefore this can as well be utilized in the push and pull strategy in stem borer management and hence compliment further the IPM strategy.

The recommendations which emanated from this study were:

1. More research should be conducted to determine the strains of *B.fusca, C. partellus* and *S.calamistis* as initially, these species had distinct ecological zones. However, they are currently found in various ecozones. Molecular techniques can be employed in this.

2. There is need to understand the moths better such that emerging aspects in their biology and reverse within host distribution of these stem borers especially in the graminae food crops to curtail food insecurity.

3. New varieties of maize and sorghum that are resistant to the havoc caused by the stem borers e.g. *Bacillus thuringiesis* sorghum [Bt Sorghum] as sorghum is cheaper to manage hence affordable by the many poor scale farmers in the County and Country at large.

4. A "push factor" i.e. a plant emitting repellants should be intercropped maize and sorghum. Their phenology should be synchronized in a manner that the peak of emitting the repellents coincide with the vulnerable phase of invasion stem borers to maize and sorghum.

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APPENDICES

APPENDIX I

1) THE DIET PREPARATION.

This followed Cook's protocol. This involved:

Fractions A, B and C were prepared as described below as treatments with the modifications:

Fraction A: All the powdered ingredients in this fraction including sucrose and vitamin E were mixed under in a clean container using a plastic spoon. The distilled water was boiled, cooled to 60^oC, and then mixed with the above mentioned pre-mixed ingredients using a blender for 1 minute. Methyl-p-hydroxybenzoate that had been dissolved in 20ml of ethanol then added into the mixture in the blender and then mixed for 2 minutes.

Fraction B: Comprised of Agar powder which was weighed in a separate container and then added to cold distilled water in a separate pan, boiled while stirring periodically, and then cooled to 60^0C. Ingredients of fraction B were added to the ingredients of fraction A in the blender and then mixed for 3 minutes to form portions to which 40% formaldehyde was added to the ingredients of fractions A and B in the blender and then mixed for 3 minutes to obtain fraction C.

An exact 200ml of diet was dispensed while warm, into heat-sterilized (65^0C for 1.5h), 1000ml capacity, wide-mouthed plastic jars (16 x 7.5 cm diameter) using a jug. After the diet was dispensed, the containers were left open for 2 hours to allow the escape of excess moisture, after which they were covered using a clean white cloth or paper towel and then left to gel condition overnight at a room temperature on a bench in the laboratory. Each of the three stem borer species was reared using the same type of plastic container described above through the 1st – 5th larvae instars.

2) DIET INFESTATION PROCEDURE.

In the jars: One egg masses (Approx. 50 eggs) were dropped on the diet per jar at the black-head stage, paper tissue was placed lining across the mouth of the jar and covered tightly with screw-cap ventilated with very fine wire mesh to prevent larval escape and the eggs for diet infestation were first sterilized following set procedure for egg sterilization.

While a different set of 3 borers comprised of three first instars larvae were put into vials using camel hair brush No. 1 (dipped in 70% ethanol and rinsed in distilled water).The vials were immediately closed with tight-fitting cotton wool plug to prevent larval escape.

All contaminated diets were discarded while pupae were collected weekly from vials. The pre-pupae were placed on paper toweling medium in a jar to pupate and, pupae were stored for up to 14 days at 10^0C to develop.

Emerging adults were put in oviposition cages which were made of aluminum frames (45L x 60H x 45W cm) with wire mesh sides and vertically sliding door. They were fed on oviposition substrate and the butter paper was pleated for *C. partellus,* and spiral for *B. fusca, S. calamistis*.

Up to 200 adults pairs were introduced into the cage and fed on water soaked in cotton wool or paper tissue, in Petri dish and replaced daily.

The Eggs that were laid were collected daily and fresh butter paper replaced. The butter paper containing eggs was cut with scissors, or scalpel blade to collect eggs in batches. Eggs surface were sterilized at black-head stage and dipped in water and dried between filter paper then stored for 3 days at 10^0C without adversely affecting hatchability.

MICROBIAL CONTAMINATION.

The possible sources of contamination included: field collected insects (Transovarial), dirty laboratory environment , visitors to the insectary and contaminated Equipment. However, pathogens include: fungus e.g. *Asparillus* spp, Bacteria e.g. *Rhizopus* spp viruses' e.g. nuclear polyhydrosis virus (NPV) and Protozoan's e.g. Nosema. These were prevented via: ensuring sanitary insectary environment, Floor- mopping with jik daily, wiping bench Tops with 70% alcohol before and after use, sterilize rearing equipment, soaking PVC in jik (household bleach) solution (200 ml jik: 60 litres water) Rinsing with water and drying at 40^0 C before use. Restricting entry into the insectary to rearing personnel, enforcing quarantine regulation for field introductions, discarding larvae and adults that have escaped as well as insects from contaminated containers, using of antimicrobial compounds in artificial diets and observing strict personnel hygiene for insectary staff was also applied.

The natural diet (from maize and sorghum) used to feed the stem borers used in this experiment was prepared as follows: Collection of insects was done from the field. *B. fusca, C, partellus* and *S. calamists* were the major species collected and taken to the laboratory, selection and separation was done from those that had infections and placed in the containers in a different room, insects were sterilized in distilled water before infestation, leaves of maize, sorghum or stalk were washed and dried before being taken to the laboratory; they were cut into small pieces of about 11cm each, the tissue paper was placed in a container before putting the which was replaced after 2 days.

The pupae were collected from the container after 30-49 days depending on the room temperature; a wet cotton wool was then placed in a Petri dish and replaced after every two days in every cage.

Eggs were collected after 6-7 days and put in a container, the small patches were then put in distilled water on a filter paper then dried and then placed in a container to hatch and jar top was covered with a tissue and lid closed tightly with a tissue paper as a cushion before putting eggs.

APPENDIX II: Damage of stem borers to unprotected maize

Unprotected maize							protected maize					
Plant No.	plant Height	exit Holes	Borers	Tunnelings	Cob Wt(g)	Grain Wt(g)	Plant Hgt(cm)	Exit Holes	Bores	Tunn Wt	Cob Wt.	Grain
1	256	1	2	11	215.9	153.6	300	0	0	0	180	136.3
2	200	2	2	8	219.9	176.0	256	0	0	0	321.9	230.7
3	177	7	0	15	215.1	167.2	222	0	0	0	227.5	181.1
4	243	7	4	26	227.0	161.5	256	0	0	0	250.0	220.0
5	187	3	0	8.6	176.2	137.1	290	0	0	0	206.7	142.9
6	158	8	7	37	129.3	98.4	219	0	0	0	293.8	232.9
7	182	3	3	14	67	41.7	284	0	0	0	249.9	200.3
8	179	1	7	28	163.5	125.3	223	0	0	0	337.7	267.1
9	253	3	0	28	95.9	48.1	280	0	0	0	173.5	140.4
10	217	2	2	11	210.8	153.5	269	0	0	0	247.5	189.2
11	237	1	0	15	207.4	164.4	232	0	0	0	207.5	164.9
12	198	1	2	9	182.8	133.4	261	0	0	0	410	308.5
13	200	2	5	15	278.4	212.7	242	0	0	0	417	334.4
14	171	4	4	36	86.5	64.5	250	0	0	0	222.7	156.9
15	167	1	2	14	11.5	84.9	247	0	0	0	291.4	188.8
Total	3047	40	34	281.6	251.3	1922.3	3 835.5	0	0	0	4037.1	3094
Mean	203.1	2.7	2.3	18.8	172.8	128.2	255.7	0	0	0	269.1	206.3

APPENDIX III: Damage of stem borers to unprotected sorghum

Unprotected sorghum								protected sorghum				
Plant No.	plant Height	exit Holes	Borers	Tunnelings	Cob Wt(g)	Grain Wt(g)	Plant Hgt(cm)	Exit Holes	Bores	Tunn	Cob Wt	Grain Wt.
1	250	1	1	9	215.7	157.4	210	0	0	0	248	160.2
2	202	1	2	8	209.9	170.0	204	0	0	0	195.1	190.7
3	178	4	0	11	215.1	168.2	160	0	0	0	240.2	181.1
4	230	5	2	16	213.0	161.5	210	0	0	0	230.0	170.3
5	185	1	0	7.6	160.2	137.1	170	0	0	0	170.7	152.1
6	140	6	5	28	109.3	74.6	138	0	0	0	148.7.	88.2
7	162	2	3	14	68.0	34.2	184	0	0	0	74.2	51.2
8	149	0	0	28	143.4	112.3	223	0	0	0	163.6	124.2
9	222	2	1	26	95.6	42.4	180	0	0	0	103.5	52.4
10	219	1	2	13	210.4	130.9	169	0	0	0	247.5	129.1
11	240	0	0	9	211.4	151.4	231	0	0	0	217.5	174.9
12	200	0	2	11	184.8	130.4	201	0	0	0	210	158.5
13	200	2	4	16	216.5	212.7	180	0	0	0	230.1	217.3
14	168	4	5	29	84.5	48.5	250	0	0	0	98.7	55.2
15	157	1	2	15	49.5	41.7	247	0	0	0	66.4	55.7
Total	2901	29	29	240.6	2347.3	1813.3	2962	0	0	0	2644.2	1951.7
Mean	193.4	1.9	1.9	16.04	156.4	120.9	197.5	0	0	0	176.3	130.1