

**ECOLOGY OF MAIZE STEMBORERS IN IRRIGATED
SUBSISTENCE FARMING SYSTEMS IN THE LIMPOPO
PROVINCE**

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“IPM is not for farmers, but by farmers.”



**“Wat julle ook al doen, doen dit van harte soos vir die Here en nie vir mense
nie” (Kol. 3:23).**

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ABSTRACT

Stemborer ecology in South Africa has been studied well but largely in maize in commercial monoculture production systems. Stemborers are important pests of maize in resource-poor farming systems at the Tshiombo irrigation scheme in the Limpopo Province, especially since crops are available throughout the year. Both irrigation and the subtropical climate make crop production possible throughout the year. Before this study no information existed on *Sesamia calamistis* (Lepidoptera: Noctuidae) moth flight patterns in South Africa and limited information on flight patterns of *Busseola fusca* (Lepidoptera: Noctuidae) in small-farming areas was available. In this study the moth flight patterns of *B. fusca* and *S. calamistis* were determined on small-scale, irrigated farms in Venda using pheromone traps. The *B. fusca* flight pattern showed two distinct peaks, the first during October (2005) and the second during December/January (2004/05). Periods of no moth flight activity occurred during December (2004). During December and January increased numbers were observed showing two peaks for *S. calamistis*. *Sesamia calamistis* moths were however also active between October and January with no activity being recorded during February. During the winter months of June and July high numbers of *S. calamistis* moths were captured. Also prior to this study no information existed on the relative abundance and natural enemies of stemborers in maize production systems such as that at Tshiombo. The incidence of damaged plants was determined on fields at monthly intervals between June 2005 and March 2006. Species distribution and population dynamics of stemborers were determined by dissecting plants at monthly intervals. Data showed that the incidence of stemborer damaged plants was highest during the months of July (2005) to February (2006) during the pre-flowering period and from June to November during the post-flowering period. The incidence of damaged plants ranged between 7 and 30 %. The stemborers that occurred were *B. fusca*, *Chilo partellus* (Lepidoptera: Pyralidae) and *S. calamistis*. *Chilo partellus*, *B. fusca* and *S. calamistis* made up 85, 5 and 7 % of the total population of stemborers, respectively. Percentage parasitism of stemborer larvae by *Cotesia sesamiae* (Hymenoptera: Braconidae) ranged between 0 and 34 % during the 15-month sampling period. This is low compared to observations in another study on *B. fusca* in maize in commercial farming systems where *Co. sesamiae* caused mortality of 90 % in diapause larvae of *B. fusca*. A study was done to determine if Napier grass would be effective as a trap crop for stemborers when planted as contour strips

along two sides of maize fields. The incidence of damaged plants and stemborer species composition on fields with Napier grass as trap crop was compared to fields without the trap crop. Fields during the whorl stage had lower incidences of damaged plants in trap crop fields compared to control fields, but only six of these were significantly lower ($P < 0.05$). The lower incidence of infestation in blocks with Napier grass as trap crop showed that this method of pest control could be effective under certain conditions. During the pre-flowering period *C. partellus* was the dominant species with proportions of between 67 and 100 % of the population in the trap fields and 88 to 100 % in the control fields. High proportions of *C. partellus* were always present in control fields with statistically significant differences between trap and control fields. Plants at different growth stages were always present and made it difficult to measure infestations compared to monoculture systems. Data showed a strong association between moth flight peaks and high larval infestations, which indicate that timing of pest management activities e.g. insecticide application could be based on the moth flight pattern. The potential for biological control of stemborers is huge and *Cotesia flavipes* (Hymenoptera: Braconidae) may be recommended for release. An integrated pest management (IPM) strategy will however only be viable if adequate advisory services exist to monitor moth flights and to assist farmers in dealing with stemborers on a sustainable level.

Keywords: *Busseola fusca*, *Chilo partellus*, IPM, irrigation, moth flight patterns, Napier grass, natural enemies, population dynamics, *Sesamia calamistis*, small-scale farming system.

OPSOMMING

TITEL: EKOLOGIE VAN STAMBOORDERS IN MIELIES IN KLEINSKAAL-BESPROEIINGSBOERDERYSTELSELS IN DIE LIMPOPO PROVINSIE

Stamboorderekologie in Suid-Afrika is goed bestudeer maar hoofsaaklik in mielies in kommersiële monokultuur-vervaardigingstelsels. Stamboorders is belangrike plaë van mielies in hulpbron-arm boerderystelsels by die Tshiombo-besproeiingskema in die Limpopo Provinsie, juis omdat gewasse regdeur die jaar aangeplant word. Die subtropiese klimaat aangevul deur besproeiing maak gewasproduksie dwarsdeur die jaar moontlik. Voor die aanvang van hierdie studie was daar geen inligting oor die vlugpatrone van *Sesamia calamistis* (Lepidoptera: Noctuidae) in Suid-Afrika nie. Daar was ook beperkte inligting rondom vlugpatrone van *Busseola fusca* (Lepidoptera: Noctuidae) in kleinboerdery-stelsels. In hierdie studie is die vlugpatrone van *B. fusca* en *S. calamistis* bepaal op kleinboer-besproeiingsplase in Venda deur gebruik te maak van feromoonvalle. Die vlugpatroon van *B. fusca* toon twee onderskeidende pieke, die eerste gedurende Oktober (2005) en die tweede gedurende Desember/Januarie (2004/05). Perodes van geen vlugaktiwiteit is tydens Desember (2004) waargeneem. Gedurende Desember en Januarie was stygende getalle waargeneem wat twee pieke getoon het vir *S. calamistis*. *Sesamia calamistis* motte was ook aktief tussen Oktober en Januarie met geen aktiwiteit gedurende Februarie nie. Tydens die wintermaande van Junie en Julie is hoë getalle van *S. calamistis* motte gevang. Voor die aanvang van hierdie studie was geen inligting beskikbaar rondom die relatiewe volopheid en natuurlike vyande van stamboorders in mielieproduksiestelsels soos by Tshiombo nie. Die voorkoms van beskadigde plante op landerye is bepaal met maandelikse intervale tussen Junie 2005 – Maart 2006. Verspreiding en bevolkingsdinamika van stamboorderspesies is bepaal deur die oopsny van plante tydens die maandelikse monsternemings. Data toon dat die voorkoms van stamboorder-beskadigde plante die hoogste was gedurende Julie (2005) tot Februarie (2006) tydens die voor-blomtydperk en vanaf Junie tot November (2005) tydens die na-blomtydperk. Die voorkoms van beskadigde plante het gewissel tussen 7 – 30 %. Die stamboorders wat voorgekom het was *B. fusca*, *Chilo partellus* (Lepidoptera: Pyralidae) en *S. calamistis*. *Chilo partellus*, *B. fusca* en *S. calamistis* het 85, 5 en 7 % van die totale bevolking van stamboorders onderskeidelik uitgemaak. Die

persentasie stamboorderlarwes wat geparasiteer was deur *Cotesia sesamiae* (Hymenoptera: Braconidae) het gewissel tussen 0 – 34 % tydens die 15-maand opnameperiode. Laasgenoemde vlakke van parasitisme is laag in vergelyke met waarnemings gedoen in 'n ander studie op *B. fusca* in mielies in kommersiële boerderystelsels waar *Co. sesamiae* mortaliteit van 90 % in diapouse-larwes van *B. fusca* veroorsaak het. 'n Studie was gedoen om te bepaal of Napiergras doeltreffend sou wees as 'n vang-gewas vir stamboorders wanneer hierdie gras geplant word as kontoere langs twee kante van mielielande. Die voorkoms van beskadigde plante en die stamboorder-spesiesamestelling op lande met Napiergras as vang-gewas is vergelyk met lande sonder die vang-gewas. Tydens die voor-blomtydperk is 'n laer voorkoms van beskadigde plante aangeteken vir die vang-gewaslande vergeleke met die ooreenstemmende kontrole lande. In slegs ses van die gevalle was die voorkoms van besmette plante in lokgewaslande betekenisvol laer ($P < 0.05$), as die ooreenstemmende kontrolelande. Die laer voorkoms van besmetting in blokke met Napiergras as vang-gewas toon dat hierdie metode van plaagbeheer effektief kan wees onder sekere omstandighede. Tydens die voor-blomtydperk was *C. partellus* die oorheersende spesie wat 67 – 100 % van die bevolking in die lokgewaslande en 88 – 100 % in die kontrolelande uitmaak. Hoë teenwoordigheid van *C. partellus* was altyd kenmerkend in kontrolelande met statisties-beduidende verskille tussen die vang-gewas en kontrole lande. Plante van verskillende groeifases was altyd teenwoordig en het die taak bemoeilik om besmettings te bepaal vergeleke met monokultuurstelsels. Data het getoon dat daar 'n sterk verwantskap was tussen motvlugpieke en hoë larwale besmettings, wat aangetoon het dat die tydsberekening van plaagbestuurspraktyke bv. insekdodertoedienings gebaseer kan word op die motvlugpatroon. Die potensiaal vir biologiese beheer van stamboorders is groot en *Cotesia flavipes* (Hymenoptera: Braconidae) word aanbeveel vir vrystelling. 'n Geïntegreerde plaagbestuurstrategie sal slegs lewensvatbaar wees indien voldoende voorligtingsdienste bestaan ten einde om motvlugte te monitor en om boere te bemagtig om stamboorders op 'n volhoubare wyse te bestuur.

Sleutelwoorde: besproeiing, bevolkingsdinamika, *Busseola fusca*, *Chilo partellus*, GPB, kleinboerderystelsels, motvlugpatrone, Napiergras, natuurlike vyande, *Sesamia calamistis*.

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CHAPTER 1: Introduction

1.1 Introduction to stemborer ecology

The indigenous maize stemborer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and the exotic sorghum stemborer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) are important pests that attack maize and sorghum in South Africa (Kfir, Overholt, Khan & Polaszek, 2001). Another stemborer, *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) is also known to attack maize plants in South Africa (Kfir, 1998) and has been reported to become more important especially under irrigation systems on the highveld plateau of South Africa (Van den Berg & Drinkwater, 2000). These three species are the only stemborers of economical importance in maize production in South Africa.

Damage symptoms to crop plants, include the destruction of apical growth points, interference with translocation of metabolites and nutrients that result in reduced yield, stem breakage, plant stunting, lodging, and direct damage to ears (Fig. 1.1) (Kfir, 1998). Stemborer infestation levels can range between 30 – 70 % in fields of subsistence farmers where no chemical control action is taken compared to less than 30 % on commercial farms where chemical control is applied to control infestations (Sithole, 1987). In the main maize producing area of South Africa, yield losses differ between farms and can range between no losses to virtually total crop loss for *C. partellus* and *B. fusca* (Van Rensburg & Bate, 1987). Although chemical control is effective against stemborers this practice is not feasible for small-scale farmers in Africa (Bonhof, Overholt, Van Huis & Polaszek, 1997).

Knowledge about the wild habitats of stemborers is important for understanding their ecology. Stemborers live within tritrophic interactions with other organisms like wild host plants and parasitoids. According to Lawani (1982) these host plants, as well as weeds and crop residues, should be eliminated completely as they may harbour stemborers, which may be destructive to cereal crops in the following season. Seshu Reddy (1983) stated that volunteer cereal hosts and wild hosts should be removed with their stubble and burnt to prevent carryover of larvae to the following season. However, wild host plants (adjacent to cultivated crops) may be important

refugia for natural enemies and may be valuable hosts to stemborer parasitoids especially after crop harvesting (Khan, Chiliswa, Ampong-Nyarko, Smart, Polaszek, Wandera, Mulaa, 1997).

Mixed species composition within the same planting complicates insecticide applications, due to the fact that registered insecticides for each species differ in terms of control measures. A solution is to develop an economic threshold model to allow for co-existence of species in varying proportions (Bate, Van Rensburg & Giliomee, 1991; Van Rensburg, Walters & Giliomee, 1988). *Busseola fusca* and *C. partellus* often occur in mixed populations within the same planting (Bate *et al.*, 1991; Van Rensburg *et al.*, 1988). Experiments with separate and mixed populations using artificial infestation on sorghum, indicated that *C. partellus* was more injurious to plants than *B. fusca* (Van den Berg, Van Rensburg & Pringle, 1990; Van den Berg, Van Rensburg & Van der Westhuizen, 1991). *Chilo partellus* may destroy stems at a greater incidence than *B. fusca* and cause more damage to plants since larval dispersal to adjacent plants is at a much higher rate than that of *B. fusca* (Van den Berg *et al.*, 1991). Kfir (1997a) speculated that *B. fusca* tends to avoid plants that were previously infested by *C. partellus*. This gives *C. partellus* an added advantage regarding the infestation of plants.

Research conducted in East and southern Africa indicated that species differ in their pattern of infestation of maize plants. In Kenya, the incidence and period of activity of the stemborer complex indicated that *C. partellus* infested sorghum early, while *S. calamistis* infested it late and persisted in the crop until it was harvested (Seshu-Reddy, 1983).

Most neonate larvae have a pre-feeding movement phase during which they locally explore the leaf or disperse over a long distance (Van Hamburg, 1980). Both *C. partellus* and *B. fusca* attack the crop early when it is in its most vulnerable stage (Kalule, Kyamanywa, Ogwang Namulonge, Omwega & Hammond, 2002). In South Africa, Van Rensburg, Walters & Giliomee (1987) observed that variation in planting date had a marked influence on levels of larval infestation. *B. fusca* preferred ovipositing 3 – 5 weeks after plant emergence when maize plants were most attractive for oviposition which resulted in a definite pattern in the time distribution of different larval instars in different plant parts (Van Rensburg *et al.*, 1987). In addition to the above species, *S. calamistis* also damages maize and sorghum seedlings in the North-West and Limpopo

Provinces (Van den Berg & Drinkwater, 2000). According to Van den Berg & Drinkwater (2000) larvae of *S. calamistis* bore directly into stems without causing damage to leaf sheaths and may infest growing points, which can lead to deadheart. *Chilo partellus* larvae and pupae can be found in the whorl, inside leaf sheaths, between the leaf sheaths and the stem and inside the stem (Van Hamburg, 1980).

The continuous presence of host plants and the warm climate in sub-tropical low-altitude areas facilitate the continuous development of *C. partellus* all-year round. Other regions with dry periods in winter or summer stimulate *C. partellus* to enter facultative diapause, a physiological resting period. In the dry season in India (Tams & Bowden, 1953), *C. partellus* enters diapause, but populations without any resting periods were reported in the coastal province of Kenya. In the highveld region of South Africa, *C. partellus* moths start to emerge from diapause larvae during the month of August and this emergence period can last until November (Kfir, 1988; 1992).

Chilo partellus displacement of other stemborer species is significant, due to the fact that it is a highly competitive coloniser. It has been observed to gradually displace *B. fusca* from maize in South Africa (Kfir *et al.*, 2001). Diapause may be a significant factor in contributing to *C. partellus* colonisation of maize plants (Bate *et al.*, 1991; Kfir, 1997a; Van Rensburg and Bate, 1987).

Emergence of *C. partellus* from diapause occurs earlier and the period over which emergence takes place is much longer than for *B. fusca* (Kfir, 1991a). *Busseola fusca* is characterised by distinct generations (Van Rensburg, Walters & Giliomee, 1985; Van Rensburg, 1997) and *C. partellus* by overlapping generations (Van Hamburg, 1987; Kfir, 1992), which is explained by the different patterns of emergence from diapause by these two borer species. These overlapping generations of *C. partellus* (Kfir, 1998) result in infestations throughout the growing season, rendering insecticide applications unsatisfactory. Thus timing of insecticide application is crucial, as sprays are only effective in controlling the young larvae (Kfir *et al.*, 2001). Older larvae penetrate stems of host plants and become inaccessible to pesticides. Based on maize yield responses, the incidence of damaged plants and internal stem injury, delayed insecticide

applications improved stemborer control especially in the period after tasseling of maize (Van Rensburg & Van den Berg, 1992).

In order to develop sound integrated pest management systems for stemborers it is essential to understand the ecology of the different stemborer species that may occur in the target area.

1.1.1 The maize stemborer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae)

1.1.1.1 Distribution and occurrence

Busseola fusca belongs to the Noctuidae family, which includes serious pests of field crops such as cutworms, bollworms and various other stemborer species and is generally regarded as the most important pest of maize in South Africa (Annecke & Moran, 1982). This species of stemborer is indigenous to Africa where maize is grown (Wale, 1999) and largely occurs at medium to high elevations.

1.1.1.2 Damage symptoms, infestations, pest status and yield loss

First instar larvae feed in whorls and may cause “shotholes”, which are the first indication of infestation after the furl leaves have unfolded. In young plants, larvae may also damage growing points, which can cause “deadheart” symptoms. From the 3rd instar onwards larvae bore into the stems and relocate to adjacent plants searching for suitable shelter in the whorl or stems (Van Rensburg *et al.*, 1987). This relocation or migration of larvae to adjacent plants is a continuous process and more plants show signs of damage when ageing while the level of primary larval infestation largely remain unchanged (Van Rensburg *et al.*, 1987).

According to Van Rensburg *et al.* (1987) there is no evidence that larvae prefer ears to stems. The infestation of the ear starts from the tip or through the husk leaves rather than *via* the stem of the ear. *Busseola fusca* may seek shelter and accidentally damage ears directly after the tasselling stage.

The pest status of *B. fusca* varies from one region to another. In East and southern Africa it occurs mainly above 600 m a.s.l. (above sea level) (Nye, 1960; Sithole, 1987). In West Africa, *B. fusca* occurs from the sea level up to 2000 m a.s.l. (Tams & Bowden, 1953) but it is primarily a pest that occurs within the dry savanna zone (Harris, 1962). According to Sithole (1989) this species occurs at elevations above 900 m a.s.l. in all countries in southern Africa, but this may differ between regions since it occurs at lower altitudes too (Sithole, 1989).

It is estimated that *B. fusca* can cause 100 % yield loss under favourable conditions (Van den Berg & Ebenebe, 2001). Migratory habits of the larvae result in a poor relationship between yield loss and visible plant damage. Larval numbers were described by Van Rensburg *et al.* (1988) as an inaccurate estimator of expected yield losses. An efficient surveying method was established where yield losses were attributed to oviposition levels because the egg batches are visible through the leaf sheaths of the host plant (Van Rensburg *et al.*, 1987). The influence of time of infestation on yield loss is a factor in determining economic threshold levels. The quantitative prediction of yield loss from season to season at a specific level of oviposition varies due to genetic differences between maize hybrids as well as climate change (Van Rensburg *et al.* 1988). Climate can play a significant role in larval dispersion to adjacent plants over a longer period (Van Rensburg *et al.*, 1987).

In terms of timing of insecticide applications for commercial farmers, small larvae are exposed and vulnerable to spraying and when infestations were observed, high mortalities could be accomplished. This general field practice should be changed according to Van Rensburg *et al.* (1987), because delayed application under certain conditions is needed to ascertain the economic importance of small infestations and to eliminate repeated applications in late plantings.

1.1.1.3 Biology of *Busseola fusca*

Busseola fusca moths are mainly active at night. Females lay their egg batches (average 30 eggs) preferably behind or under the youngest, vertical edges of unfolded leaf sheaths and outer husk leaves of the ear (Van Rensburg *et al.*, 1987).

Eggs hatch after several days after which larvae migrate upwards on the outside of the plant (Kfir, 1998). Larvae prefer to feed on young rolled furl leaves. The larvae may disperse to adjacent plants and may infest approximately three neighbouring plants. During the third instar, larvae bore into stem tissues and maize ears (Kfir, 1998). Under optimum conditions the duration of the larval stage is six weeks. Pupation always occurs in stems (Kfir, 1998).

The first seasonal moth flight originates from larval populations in late spring (Van Rensburg *et al.*, 1985; Kfir, 1998). A second seasonal moth flight during which the moths lay eggs on late planted maize lasts up to three weeks and is separated from the first flight by a distinct period of approximately three weeks when second generation larvae emerge (Van Rensburg *et al.*, 1985). A relatively small number of larvae enter the pupal stage and thus results in a third late season moth flight. These moths do not provide offspring because the plants are too old for oviposition and 2nd instar larval feeding. Mature diapause larvae over-winter in the stem base of the maize plant in a position just below the soil surface and give rise to moths during the following season.

Busseola fusca oviposit selectively on the most vigorous plants in maize plantings (Van den Berg & Van Rensburg, 1991). Plantings should only be monitored for infestations during the egg-laying period, three to six weeks after plant emergence. This information can be used to determine the timing of pest management activities (Van Rensburg *et al.*, 1987). This is quite a challenge in subsistence farming, especially where planting occurs continuously and plants of different growth stages are present at the same time.

1.1.2 The sorghum stemborer: *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae)

1.1.2.1 Distribution and occurrence

Chilo partellus belongs to the family Pyralidae and is an economically important pest at elevations below 1500 m a.s.l. (Greathead, 1990). Other *Chilo* species include: *C. orichalcociliellus* (Strand) which was recorded in South Africa and is a pest of maize and sorghum in East Africa and *C. agamemnon* (Bleszynski), a pest of maize in the Middle East. Also, *C. sacchariphagus* (Bojer), which is a pest of sugarcane, was recorded in East Africa

(Maes, 1997). These stemborers infest maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), millet (*Panicum miliaceum* L.) (Seshu Reddy, Lubega & Sum, 1990) and sugarcane (*Saccharum officinarum* L.) (Maes, 1997).

Chilo partellus is native to Asia and the Indian sub-continent (Harris, 1989) and it was first recorded in Malawi in 1932 (Tams, 1932). It has spread to eastern and southern Africa (Mohyuddin and Greathead, 1970; CABI, 1989) often becoming the most injurious stemborer (Kfir, 1997b & Seshu Reddy, 1983).

In a study by Overholt, Ogedah & Lammers (1994) in Kenya, *C. partellus* was observed to account for more than 80 % of stemborers collected. During early larval stages highly dispersive behaviour is observed during which larvae spin silken threads and migrate to adjacent plants.

1.1.2.2 Damage symptoms, infestations, pest status and yield loss

According to Schulthess, Bosque-Perez & Gounou (1991), visual estimation of infestation levels underestimates the percentage of infested plants compared to actual infestation levels when plants are dissected. It can be concluded that the incidence of plants exhibiting whorl damage is always different from those with actual damage. For research purposes, through enumerative sampling, detailed information can be gathered like species identification, life stages and parasitoid identification.

According to Van den Berg & Van Rensburg (1991) the economic threshold for insect control should be based on a measure of insect infestation, which would warrant the cost for chemical control. The changes in yield potential of crops are assumed to be accommodated by the expected yield loss as a percentage of potential yield in the absence of the pest. The assumption that a given level of infestation relates to a proportional loss does not always hold true (Walker, 1981).

In a study by Van den Berg & Van Rensburg (1991), the number of damaged stems (visual plant damage) in comparison with infested stems (actual larval numbers / plant) was always higher, irrespective of the crop growth stages or infestation level. The incidence of whorl damage is a

parameter used to estimate yield loss in economic threshold models. There may be different yield trends with increased infestation levels where low infestations are associated with yield increases and further yield responses are dependent on both infestation level and the occurrence of tillering. Time of infestation may be more important than the degree of damage or level of infestation (Van Rensburg & Van den Berg, 1992). *Chilo partellus* may infest up to 100 % of plants, resulting in significant yield losses e.g. in Mozambique (Nunes, Sousa & Sataric, 1985). Yield losses can range from 24 – 36 % in maize and 2 – 88 % in sorghum (Overholt *et al.*, 1994).

1.1.2.3 Biology of *Chilo partellus*

According to Harris (1989), *C. partellus* adults emerge from pupae in stems (with activity at night), after which the males mate with females. According to Kfir (1998) females prefer laying their eggs in batches of 10 – 80 overlapping eggs parallel to the long axis of the abaxial side of the leaves. A few days later, larvae hatch and migrate to adjacent plants where they move up the leaf whorl to feed on young leaves and penetrate the stem. *Chilo partellus* larvae tunnel inside stems and then pupate in the stem after excavating emergence windows for moths to escape (Kfir, 1988).

Chilo partellus has a higher potential rate of increase than other stemborers (Kfir, 1997a). Larvae survive the dry winters (subzero temperatures) of the Highveld region in South Africa by diapausing low in the dry stalks, often beneath the soil.

1.1.3 The pink stemborer: *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae)

1.1.3.1 Distribution and occurrence

Sesamia calamistis is indigenous to Africa and is distributed all-over, especially sub-Saharan Africa where great damage is done to a variety of crops (Harris, 1989). According to Harris (1962) and Overholt & Maes (2000), *S. calamistis* is economically insignificant, in East and southern Africa, and occurs at very low infestation levels. This genus, which is prevalent at medium elevations, includes other *Sesamia* spp. (distribution follows in brackets): *S.*

nonagrioides (Levebre) (West Africa), *S. cretica* (Lederer) (North-east Africa) and *S. inferens* (Walker) (South-east Asia). During a survey by Seshu-Reddy (1983), *S. calamistis* was recovered in many areas of Kenya, from sea level up to 1400 m a.s.l. (Ingram, 1958). In East Africa, Nye (1960) recorded this stemborer at all altitudes (up to 2400 m) and it was reported common in the hills, lakes and irrigated areas. *Sesamia calamistis* also occurs in maize under irrigation in the Limpopo and North West Provinces where it may cause serious maize stand losses (Van den Berg & Drinkwater, 2000).

1.1.3.2 Damage symptoms, infestations, pest status and yield loss

Host plants of *S. calamistis* include rice (*Oryza sativa* L.), common wheat (*Triticum aestivum* L.) and elephant grass (*Pennisetum purpureum* Schumacher). The symptoms of damage caused by *S. calamistis* include 'dead heart' and increased tillering with no feeding marks on leaves but only an external borer-hole which is found at the base of the stem (Sithole 1989). This noctuid, in conjunction with *B. fusca* and *Eldana saccharina* (Walker) (Lepidoptera: Pyralidae), can cause yield losses up to 100 % in West Africa and can be a major constraint to maize production in Benin, Ghana and the Ivory Coast (Gounou & Shulthess, 2004).

During late summer and autumn maize plants may have high infestation levels of *S. calamistis*. In Limpopo and North-West Provinces damage is mainly done to maize and sorghum during seedling stages (Van den Berg & Drinkwater, 2000). Data obtained by Waladde, Van den Berg, Botlohle & Mlanjeni (2001) in the Eastern Cape Province suggested *S. calamistis* infestations between 26 – 75 % with densities ranging between 0 – 13 larvae/plant. Fluctuations in population levels are erratic with no distinct periods of emergence of adults as in the case of *B. fusca* (Harris, 1962).

1.1.3.3 Biology of *Sesamia calamistis*

Sesamia calamistis develop throughout the year with no resting phase and complete its life cycle in approximately 41 days at 26 °C and 71 days at 21 °C (Van den Berg & Drinkwater, 2000). In Nigeria, even during the very dry season, no resting stage occurs and development continues

throughout the year (Harris, 1962). According to Ingram (1958) batches of up to 20 eggs are laid under leaf sheaths with first instar larvae boring straight into stems or ears after one week with distinctive feeding periods in the leaf whorl. This is in marked contrast to behaviour of first instar *B. fusca* larvae. According to Harris (1962), this behaviour of entering the stem, resembles more closely the behaviour of *C. ignefusalis*, a dominant stemborer on pearl millet in the Sahelian zone. In older plants eggs are laid in the axils where young maize ears form (Van den Berg & Drinkwater, 2000). Larval development is completed after 6 – 10 weeks in the stem. Pupae may be found in the stem, between the ear leaves or in the ear. The pupal stage lasts between 10 – 12 days after which the moths emerge (Sithole, 1989).

1.2 Ecology of parasitoids

1.2.1 Tritrophic interactions

Many contemporary agricultural plants have been modified by artificial selection. These modifications present new physical, chemical and behavioural constraints to foraging parasites, and may have created refuges for stemborers, inhibiting or precluding the adaptive foraging patterns of parasites that evolved with the ancestral crops (Smith & Wiedenmann, 1997).

Agricultural practices are known to influence parasitism of pests. The percentage parasitism of all three stemborer species by *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) was higher in maize intercropped with other crops, such as haricot bean (*Phaseolus vulgaris*) and cowpea (*Vigna unguiculata*), than in maize monocultures and in the presence of wild grasses (*Pennisetum purpureum*, *Sorghum verticilliflorum*, *Hyparrhenia* spp. and *S. vulgare* var. Sudanese) than when no wild hosts were found (Getu, Overholt, Kairu & Omwega, 2003). Parasitism of *C. partellus* by *Co. flavipes* was significantly higher than parasitism of *B. fusca* and *S. calamistis* (Getu *et al.*, 2003). Root's enemy hypothesis may explain the higher parasitism by *Co. flavipes* in intercropping systems than in monocropped maize. In Ethiopia over 50 % of the farmers grow maize and sorghum in an intercropped system with other crops (Getu, Overholt & Kairu, 2001). The better performance by *Co. flavipes* in an intercropped system compared to monocultures could favour population growth of the parasitoid in Ethiopia. Rische, Andow & Altieri (1983) found that vegetation in the proximity of crops significantly affected the abundance of natural

enemies and the pest. There was higher parasitism by *Co. flavipes* when stemborer wild hosts were present in the vicinity of maize or sorghum, than when there were no wild hosts, implying that wild host plants sustain stemborers, which *Co. flavipes* can exploit, especially when susceptible stemborer stages are not found in crop stands (Overholt, Ngi-Song, Omwega, Kimani, Mbapila, Sallam & Ofomata, 1997).

1.2.2 Foraging strategies and guilds of parasitoids

The parasitoids foraging strategies are central to determining the ecological equivalency of parasitoids for identifying candidate parasitoids for importation of biological control programmes (Wiedenmann & Smith, 1997).

Parasites can be organised into guilds according to the host stage they attack (Miller & Ehler, 1990). Using Mills' guild classification scheme, stemborers have for example egg endoparasites, larval ectoparasites and larval-pupal endoparasites (Smith, Wiedenmann & Overholt, 1993). The particular host stage attacked and the microhabitat containing the host defines the environment searched by the female parasitoid. The method of host attack includes direct, probe-and-sting, drill-and-sting, wait-and-sting and ingress-and-sting (Smith & Wiedenmann, 1997).

Physiological suitability of the host is an absolute necessity for successful development of the parasitoid progeny because of the intimate relationship between endoparasitoid progeny and its host (Hailemichael, Schulthess, Smith & Overholt, 1997).

1.2.3 The larval parasitoids *Cotesia sesamiae* (Cameron) and *Cotesia flavipes* (Cameron)

Ingress-and-sting parasitoids are typically small parasitoids that parasitize late instar larvae or pupae. These parasitoids enter the external openings to the larval feeding tunnel or the exit tunnel associated with the pupal chamber. These parasitoids include microgastrine braconids like the larval parasitoids *Co. flavipes* and *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae).

Both parasitoids, *Co. flavipes* and *Co. sesamiae*, are ecologically similar and can complete development in *C. partellus* and *S. calamistis*, which are two of the main species occurring in Kenya (Ngi-Song, Overholt & Ayerty, 1995). *Cotesia sesamiae* accounted for only 0.5 – 3 % mortality of late instar *C. partellus* larvae in coastal Kenya and does not appear to be a very effective natural enemy (Overholt, Ngi-Song, Kimani, Mbapila, Lammers & Kioko, 1994). Laboratory studies suggested that *Co. flavipes* was superior to *Co. sesamiae* when *C. partellus* was the host (Ngi-Song *et al.*, 1995; Mbapila, 1994).

Because of the economic importance of *C. partellus* and its status as an introduced pest, it has been a target of classical biological control attempts in South Africa (Kfir, 1994). Thus far, the only natural enemy to become established was *Co. flavipes*, which now occurs in several countries in East and southern Africa (Overholt, 1998). *Cotesia sesamiae* does not appear to be effective in regulating population densities of the exotic pest *C. partellus* at a level acceptable to farmers (Overholt *et al.*, 1994).

Chilo partellus has significant strategies to protect itself against natural enemies. When larvae are in diapause they are protected from natural enemies by a robust plug or cocoon (Kfir, 1988) and do not produce frass, which is an important cue in host location by parasitoids (Mohyuddin, 1971). *C. partellus* reacted aggressively (biting or spitting) against *Co. flavipes* when stung (Potting, Osae-Danso, Overholt & Ngi-Song, 1993). Parasitoid mortality does occur and is influenced by host stage (older larvae), direction of attack (head versus abdomen) and previously parasitized hosts (Takasu & Overholt, 1997). The rapid oviposition of *Co. flavipes* soon after encountering the host, is a strategy which allows them to successfully parasitize aggressive hosts and in some cases 96 – 100 % of hosts were parasitized (Takasu & Overholt, 1997). *Co. flavipes* produced significantly more progeny on large-sized larvae of *C. partellus* than on medium or small-sized larvae (Omwega & Overholt, 1997).

During foraging, stemborer parasitoids are aided by semio-chemicals to locate hosts. These compounds can be derived from the herbivore itself or by activities related to the biology of herbivores, the host plant or from plant-herbivore interactions (Dicke & Sabelis, 1988). According to Turlings, Loughrin, McCall, Röse, Lewis & Tumlinson (1995) volatiles produced

by plants in defence to stemborer attack are useful for parasitoid location (herbivore-induced synomones). This preference for infested plants was reported by Ngi-Song, Overholt, Njagi, Dicke, Ayerty & Lwande (1996) as important cues for females of both *Co. flavipes* and *Co. sesamiae*. *Cotesia flavipes* and *Co. sesamiae* cannot discriminate between host plants infested by *C. partellus*, *B. fusca* and *S. calamistis* (Potting *et al.*, 1993; Ngi-Song *et al.*, 1996). Thus variability in the host suitability of various host/parasitoid combinations may lead to one species having a consistent advantage over the other (Sallam, Overholt & Kairu, 2002). Ngi-Song *et al.* (1996) suggested that *Co. flavipes* is rather more attracted to plants that have a larger number of stemborers infesting them, due to the larger quantities of volatiles being produced. The response of the small ingress-and-sting braconid, *Co. sesamiae*, to synomones and kairomones (chemical cues associated with host by-products, such as larval frass) for host finding provides a specific example of a chemical refuge (Smith & Wiedenmann, 1997). *Cotesia flavipes* females exhibit a greater attraction to synomones from stemborer-infested maize than infested *Sorghum* spp. (Ngi-Song *et al.*, 1996).

1.2.4 Biology of *Cotesia flavipes* (Cameron)

Cotesia flavipes has a short adult lifespan of a few days and an initial egg load of about 150 eggs. The egg-to-adult development time is around 20 days and the sex ratio is usually female biased (60 – 70 %) (Potting, 1997). A female *Co. flavipes* deposits about 40 eggs in a host larva per one sting and the highest reproductive success is on the latter larval instars (4 – 6th) (Potting, 1997) where one female may parasitize up to four host larvae (Ngi-Song *et al.*, 1995).

1.2.5 The pupal parasitoid *Dentichasmias busseolae* (Heinrich)

Dentichasmias busseolae (Heinrich) (Hymenoptera: Ichneumonidae), an ingress-and-sting pupal parasitoid is known as an important parasitoid of *C. partellus* in East Africa and occurs in the Ethiopian Region in a wide range of climates (Mohyuddin, 1972). It attacks its host by drilling with the ovipositor through the plant tissue and laying a single egg in the pupa. In South Africa *D. busseolae* was found to be the most abundant pupal parasitoid at Brits, reaching up to 100 % parasitism. It was also reared from *B. fusca* (Kfir, 1990a). Although pupal parasitoids play an

important role in reducing the population levels of *C. partellus* and the other common stemborer species, they are not able to reduce pest numbers to acceptable levels (Gitau, Ngi-Song, Overholt & Otieno, 2002). In the Highveld region of South Africa activity by pupal parasitoids was found to be negligible (Kfir, 1995).

1.2.6 Biological control in South Africa

The high cost and inefficacy of insecticidal control of *C. partellus* and *B. fusca* brought about the initiation of a biological control programme using exotic parasitoids as a possible control method against stemborers in South Africa (Kfir, 1991b). Studies by Van Achterberg & Walker (1998), Kfir (1994), Zwart (1998), Polaszek, LaSalle & Jongema (1998) and Carnegie, Conlong & Graham (1985) indicated that many parasitoid species occur on stemborers in South Africa (Table 1). However, there has been a lack of success in biocontrol of *C. partellus* in South African maize. Because activities of natural enemies increase only towards the end of the growing season, they do not exert a pronounced effect on stemborer populations during the growing season. They can, however, play an important role in reducing the size of overwintering populations (Van den Berg & Ebenebe, 2001). Indigenous parasitoids do not seem able to maintain stemborer populations at economically acceptable levels (Kfir, 1992; Kfir & Bell, 1993; Overholt *et al.*, 1994).

On the South African Highveld region and KwaZulu-Natal (Delmas and Cedara), eighteen parasitoid species were recorded from *B. fusca* on maize and grain sorghum (Kfir, 1995). In Delmas, larval parasitism of *B. fusca* fluctuated below 20 % and occasionally peaked between 40 – 60 % (Kfir, 1995). Parasitoids were active all season long and peaked during January, March and April. At Cedara, a 100 % pupal parasitism was observed during February and March and 80 % during November when parasitoids attacked *B. fusca* pupae (Kfir, 1995).

Cotesia sesamiae is common in the wetter parts of Africa with parasitism levels of 20 % at the Kenyan coast and in Uganda (Skovgård & Päts, 1996). This larval parasitoid may also be highest in abundance among other parasitoids like *Bracon sesamiae* (Cameron) (Hymenoptera: Braconidae), which is the second most abundant of the larval parasitoids. The pupal parasitoids,

D. busseolae and *Pediobius fuscus* (Gahan) (Hymenoptera: Eulophidae) are important in suppressing *C. partellus* populations in South Africa (Kfir, 1990b; 1992). Although both stemborer parasitoids *Co. flavipes* and *Co. sesamiae* successfully parasitize diapausing larvae in the laboratory, it is not possible for these parasitoids to locate them in dry crop residues in the field (Kfir 2001).

As mentioned, larval parasitoids like *Co. flavipes* and *Co. sesamiae* can exploit more than one of the hosts in the target habitat (Kfir *et al.*, 2001). This wide host range makes these parasitoids better colonisers, as there is a more constant availability of hosts and a lack of population growth depression due to wasting eggs in attractive but unsuitable hosts. Gregarious reproduction may predispose *Co. flavipes* and *Co. sesamiae* to establish (Kfir *et al.*, 2001). *Cotesia flavipes* has a high host-searching ability and even at low densities *Co. flavipes* can successfully locate stemborer hosts, as observed by Wiedenmann & Smith (1993). The high host-searching success of *Co. flavipes* may in part be due to behaviour of entering stem tunnels to parasitize stemborer larvae (Smith, Wiedenmann & Overholt, 1993). Many other larval parasitoids attack their hosts by drilling, or locating breaches through the stem with their ovipositor (Smith *et al.*, 1993). The length of the ovipositor may limit the number of hosts susceptible to attack (Kfir *et al.*, 2001), especially in larger-stemmed cultivated grasses such as maize.

Cotesia flavipes has been released in many tropical and subtropical countries for biological control of exotic and native stemborers (Polaszek & Walker, 1991). In mainland Africa *Co. flavipes* has been released against *C. partellus* (Kfir, 1994) resulting in establishment in Kenya (Omwega, Kimani, Overholt & Ogol, 1995). Parasitism may depend on location and season and varied between 0 – 26 % at the Kenyan coast (Mathez, 1972). In South Africa efforts have been made by Kfir (1994) to control *C. partellus* using a biological agent *Co. flavipes*. *Cotesia flavipes*, an indigenous species to South and South-east Asia (Mohyuddin, 1971; Kfir 2001), was introduced from Pakistan for biological control of *C. partellus* in coastal Kenya and caused a 32 – 55 % decrease in stemborer density (Kfir *et al.*, 2001). In East Africa, biological control efforts were implemented against *C. partellus* by releasing *Co. flavipes* at the Kenyan coast. *Cotesia flavipes* became established and was recovered from the coast (Overholt *et al.*, 1994).

Cotesia flavipes may only establish in areas where the predominant stemborer species are suitable for its development, like its association with *C. partellus*. Old host-parasitoid interactions are more likely to occur than do new host-parasitoid associations (Kfir *et al.*, 2001). Behaviour and physiological compatibility of old associations are implicit, whereas in new associations compatibility cannot be assumed (Wiedenmann & Smith, 1997). The probability of establishment and the level of suppression of the stemborer complex may depend not only on the old host-parasitoid relationships but also on the compatibility of the new relationships (Kfir *et al.*, 2001).

In order to understand the ecology of stemborers and to develop integrated pest management systems for these pests an understanding of the natural enemy complex is needed. Research on the distribution patterns of stemborer species and parasitoids over time will provide valuable information on ecology and will assist in development of sustainable management strategies including the release of biocontrol agents and use of cultural control methods.

1.3 Stemborer moth flight patterns in South Africa

1.3.1 Moth flight patterns of *Busseola fusca*

Knowledge regarding moth flight patterns may be useful in the development of pest management strategies. The timing of insecticide applications against *B. fusca* in commercial monoculture systems can be effectively based on moth flight patterns (Van Rensburg, 1997). However, in small-farming systems, chemical control is rarely used for stemborers. Knowledge of moth flight patterns can be used to develop cultural control strategies and can be useful to determine timing of the release phase in a biological control programme. The moth flight pattern of *B. fusca* has been studied well by Van Rensburg *et al.* (1985) and Van Rensburg (1992; 1997), but no studies have previously been done on *S. calamistis* flight patterns.

In the Highveld region of South Africa the *B. fusca* moth flight pattern is characterised by two and sometimes three distinct flight periods. These moth flight patterns explain seasonal variation and could serve as an early warning system for possible stemborer outbreaks based on general planting date, the season and locality (Van Rensburg, 1997).

Moth flights between three and five weeks after plant emergence make the most important contribution to total infestation in a specific planting. In terms of the egg-laying pattern this period was identified between four and six weeks after plant emergence for *B. fusca* (Van Rensburg *et al.*, 1987).

Stemborer infestation levels were shown to be influenced by planting time (Swaine, 1957; Harris, 1962). Late planted maize is generally more severely infested than early plantings. During December there is a period of low moth activity. Maize planted in mid-November would be in the most susceptible growth stages during this period, and low infestation levels are often experienced in such plantings, even in years of increased stemborer infestation levels (Swaine, 1957; Harris, 1962). The effect of planting date on infestation levels can be pronounced. Infestation levels decrease with a delayed planting date until about mid-November after which it increased again (Van Rensburg *et al.*, 1987).

1.3.2 Pheromone traps

Pheromone-baited traps are useful devices for monitoring moth population levels of stemborers. Trap catches of male moths can provide useful information for the timing of insecticide applications (Van Rensburg, 1992; Van Rensburg, 1997).

1.3.3 Moth flight patterns in small-scale farming systems

Since limited information is available on moth flights of especially *S. calamistis* in resource-poor farming areas of South Africa, research is needed in this regard. This will enable identification of periods of low moth activity, which could possibly be used in planning of planting dates of maize so that the most susceptible growth stages do not coincide with high levels of infestation.

Stemborer research in small-scale farming systems in South Africa was limited to *B. fusca* moth flight pattern studies (Van Rensburg, 1997) and surveys of stemborers in the Eastern Cape (Waladde *et al.*, 2001). No research on ecology in irrigation systems in sub-tropical areas has yet been done.

1.4 Habitat management and their adaptations

1.4.1 Trap cropping

Stemborers may occur on various wild and cultivated members of the Gramineae. *Chilo partellus* prefers maize to sorghum but also survives on Sudan grass (*Sorghum vulgare* L. Pers.), Johnson grass (*Sorghum halepense* L. Pers.), Napier grass (*P. purpureum*) and buffalo grass (*Buchloe dactyloides* Nutt.) (Khan *et al.*, 1997; Van den Berg, Rebe, Du Bruyn & Van Hamburg, 2001).

Habitat modification through the use of alternate hosts in the surroundings of cultivated crop fields may be implemented as a cultural control measure to control stemborer pests (Khan, Pickett, Van den Berg, Wadhams & Woodcock, 2000). Trap cropping may be utilised, which has economic and environmental benefits (Hokkanen, 1991). Ovipositing female moths of stemborers may be attracted to indigenous host-plant species. These trap crops may cause high mortality of neonate larvae where survival is reduced to zero (Khan *et al.*, 1997; Van den Berg *et al.*, 2001).

Host plants may enhance parasitoid and natural enemy activity, which reduces stemborer infestations on adjacent crops (Khan *et al.*, 1997) and concentrates them in the trap crop to enhance natural occurring biological control (Hokkanen, 1991).

1.4.2 *Pennisetum purpureum* (Schumacher) as trap crop

Recent studies revealed the important role of wild host plants in stemborer ecology in Kenya. According to Van den Berg, Nur & Polaszek (1998), *P. purpureum* can be used as trap plant in stemborer management. *P. purpureum* and Guinea grass (*Panicum maximum*) commonly grown near farmers' fields are important refugia for natural enemies including *Co. flavipes* and *Co. sesamiae* after the crop is harvested, and may be important in the ecology of natural enemies (Van den Berg *et al.*, 1998).

1.4.3 The ‘push-pull’ habitat management system

The preference of stemborer moths to oviposit on certain wild host plants was exploited in an initiative by the International Centre of Insect Physiology and Ecology (ICIPE) to alleviate damage done to maize crops. In this approach a habitat management strategy called “stimulo-deterrent diversion strategy” (SDDS) or ‘push-pull’ (Miller & Cowles, 1990) strategy was developed. A combination of deterrent and attractant plants is used to direct the pest species (stemborer e.g. *C. partellus*) to a selected site (trap crop e.g. Napier grass). In this SDDS, maize is thus intercropped with a repellent plant, *Desmodium uncinatum* (Jacq.) (silver leaf desmodium) while an attractant plant, *P. purpureum* is planted as a trap around the field (Khan *et al.*, 1997; 2000). Gravid female moths are repelled away from the maize by the intercrop (push) and are attracted to the Napier grass (pull) in a ‘push-pull’ strategy (Khan *et al.*, 1997; 2000). According to Van den Berg *et al.* (2001), Napier grasses are the preferred host for oviposition by *C. partellus* moths with a subsequent high level of larval mortality on this host.

1.4.4 Trap cropping in the Limpopo Province

The value of Napier grass in the Limpopo Province of South Africa primarily lies in the prevention of soil erosion (Van den Berg *et al.*, 2001). Local farming conditions and farmers’ preferences resulted in adaptations to the habitat management system that is used by farmers in East Africa. Desmodium is not included in the local system and apart from its absence there has also been an adaptation in the spatial arrangement of the Napier grass trap crop. The grass is not planted as a barrier around maize fields but only as long contour strips along two sides of fields. Fields are therefore no longer surrounded by Napier grass on four sides but only along contours. Since this adapted system does not include all the components of the push-pull system, the Napier grass only functions as a trap crop. The value of the crop and the economic injury levels of the key pest affect economic successes of using trap crops (Hokkanen, 1991). If a trap crop is different from the main crop, but is useful for animal feed, green manure or as a nursery for natural enemies useful in adjacent crops, the economics of it is still more favourable.

1.4.5 Control of stemborers in a diverse habitat

Due to a bigger biodiversity among grass habitats, which is suitable or less suitable hosts for stemborer species, the entire grass community will always yield aggregated distribution of stemborers (Gounou & Schulthess, 2004). According to Andow (1991) it is important to know how arthropods respond to polycultures compared to monocultures because there are different plant combinations and shuffling of the herbivore and natural enemy fauna. In theory the diversity-stability hypothesis states that the greater the biodiversity of a community of organisms, the greater stability of that community (Andow, 1991). Andow (1991) stated that pest populations should be suppressed and not stabilised to control pest populations and to reduce the magnitude of population fluctuations of the pest but large pest populations are intolerable so the goal should be to lower pest population density (Murdoch, 1975; Stern, Smith, Van den Bosch & Hagen, 1959; Van Emden & Williams, 1974).

1.5 The Tshiombo irrigation scheme

1.5.1 Location of study site

The Tshiombo irrigation scheme (Fig. 1.2 – 1.4) lies at the western end of the Tshiombo valley, north-east of Thohoyandou in the Limpopo Province. On the upper reaches of the Mutale River, irrigated lands cover an area of 1,196 ha, divided into 930 plots, each of approximately 1.2 ha in size (Lahiff, 1997).

1.5.2 Stemborers as pests

Stemborers are important pests of maize at the Tshiombo irrigation scheme. A habitat management system is currently used by resource-poor farmers in this area of Venda. As described previously, three stemborer species have been observed to occur at the scheme and high levels of stemborer infestation have been observed. The stemborer species that were reported were *B. fusca*, *C. partellus* and *S. calamistis*.

1.5.3 Principal objectives

No information exists on the ecology of stemborers and their natural enemies in sub-tropical maize production systems such as that at Tshiombo. The potential for biological control of stemborers is huge once baseline information has been collected, especially in the case of *C. partellus*, which is an exotic species.

The aim of this project was to study the occurrence and relative abundance of graminaceous stemborers and their natural enemies at an irrigation driven agricultural system and to evaluate aspects of habitat management. This information may be used to develop environmentally-friendly and socially-acceptable pest management strategies at this and similar irrigations schemes in the region.

Research on stemborers at the Tshiombo irrigation scheme was addressed under the following topics:

- stemborer moth flight patterns;
- occurrence and relative abundance of stemborers and their parasitoids;
- the effect of Napier grass trap crops on stemborer infestation levels in maize fields.

1.6 References

- ANDOW, D.A. 1991. Vegetational diversity and arthropod population response. *Ann. Rev. Entomol.* 36: 561-586.
- ANNECKE, D.P. & MORAN, V.C. 1982. Insects and Mites of cultivated plants in South Africa. *Butterworths & Co.* Durban, South Africa. 383 pp.
- BATE, R., VAN RENSBURG, G.D.J. & GILIOME, J.H. 1991. Distribution and occurrence of the stem-borer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) on maize in South Africa. *J. Afr. Zool.* 105: 11-15.
- BONHOF, M.J., OVERHOLT, W.A., VAN HUIS, A. & POLASZEK, A. 1997. Natural enemies of cereal stemborers in east Africa: A review. *Insect Sci. Appl.* 17: 19-35.
- CABI., 1989. *Chilo partellus* (Swinh.). Distribution Maps of Pests. *Series A (Agriculture)*. No. 184. *Int. Inst. Entomol.* London.
- CARNEGIE, A.J.M., CONLONG, D.E. & GRAHAM, D.Y. 1985. Recent introductions of parasitoids against *Eldana saccharina* (Walker) (Lepidoptera: Pyralidae). *Proceedings of the South African Sugar Technologists' Association* pp. 160-163.
- DICKE, M. & SABELIS, M.W. 1988. Infochemical terminology: should it be based on cost-benefit analysis rather than origin of compounds. *Func. Ecol.* 2: 131-139.
- GETU, E., OVERHOLT, W.A. & KAIRU, E. 2001. Distribution and species composition of stem borers and their natural enemies in maize and sorghum in Ethiopia. *Insect Sci. Appl.* 21: 353-359.
- GETU, E., OVERHOLT, W.A., KAIRU, E. & OMWEGA, C.O. 2003. Evidence of establishment of *Cotesia flavipes* (Hymenoptera: Braconidae), a parasitoid of cereal stemborers, and its host range expansion in Ethiopia. *Bull. Entomol. Res.* 93: 125-129.

GITAU, C.W., NGI-SONG, A.J., OVERHOLT, W.A. & OTIENO, S.A. 2002. Pupal parasitoids of sub-Saharan African cereal stem borers and the potential for introduction of an exotic species – *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae). In: Tenywa, J.S., Nampala, M.P., Kyamanywa, S, Osiru, M., eds. *Integrated Pest Management Conference Proceedings. Afr. Crop Sci. J.* pp. 10-17. Kampala, Uganda.

GOUNOU, S. & SCHULTHESS, F. 2004. Spatial distribution of lepidopterous stem borers on indigenous host plants in West Africa and its implications for sampling schemes. *Afr. Entomol.* 12: 171-178.

GREATHEAD, D.J. 1990. Utilization of natural enemies of *Chilo* spp. for management in Africa. *Insect Sci. Appl.* 11: 749-755.

HAILEMICHAEL, Y., SCHULTHESS, F., SMITH, J.W., JR. & OVERHOLT, W.A. 1997. Suitability of West African gramineous stemborers for the development of *Cotesia* species. *Insect Sci. Appl.* 17: 89-95.

HALL, R.W. & EHLE, L.E. 1979. Rate of establishment of natural enemies in classical biological control. *Bull. Entomol. Soc. Am.* 25: 280-282.

HARRIS, K.M. 1962. Lepidopterous stem borers of cereals in Nigeria. *Bull. Entomol. Res.* 53: 139-171.

HARRIS, K.M. 1989. Recent advances in sorghum and pearl millet stem borer research. In: Nwanze, K.F., ed. *Int. Worksh. Sorgh. Stem Borers, Patancheru, 1987*. ICRISAT Sahelian Center, Niamey, Niger. Patancheru 502 324, Andhra Pradesh, India: International Crop Research Institute for the Semi-Arid Tropics pp. 9-16.

HOKKANEN, H.M.T. 1991. Trap cropping in pest management. *Ann. Rev. Entomol.* 36: 119-138.

INGRAM, W.R. 1958. The Lepidopterous stalk borers associated with Gramineae in Uganda. *Bull. Entomol. Res.* 49: 367-383.

KALULE, T., KYAMANYWA, S., OGWANG NAMULONGE, J.A., OMWEGA, C.O. & HAMMOND, R. 2002. Establishment of *Cotesia flavipes*, a parasitoid of the stalk borer *Chilo partellus*, in selected districts of Uganda. *International Centre for Insect Physiology and Ecology (ICIPE), National Agricultural Research Organisation (NARO) and the IPM/CRSP program.*

KHAN, Z.R., CHILISWA, P., AMPONG-NYARKO, K., SMART, L.E., POLASZEK, A., WANDERA, J. & MULAA, M.A. 1997. Utilization of wild gramineous plants for management of cereal stemborers in Africa. *Insect Sci. Appl.* 17: 143-150.

KHAN, Z.R., PICKETT, J.P., VAN DEN BERG, J., WADHAMS, L.J., WOODCOCK, C.M. 2000. Exploiting chemical ecology and species diversity: stem borer and striga control for maize and sorghum in Africa. *Pest Manag. Sci.* 56: 957-962.

KFIR, R. 1988. Hibernation by the lepidopteran stalk borers, *Busseola fusca* and *Chilo partellus* on grain sorghum. *Entomol. Exp. Appl.* 48: 31-36.

KFIR, R. 1990a. Parasites of the spotted stalk borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in South Africa. *Entomophaga* 35: 403-410.

KFIR, R. 1990b. Prospects for cultural control of the stalk borers, *Chilo partellus* and *Busseola fusca*, in summer grain crops in South Africa. *J. Econ. Entomol.* 84: 1677-1680.

KFIR, R. 1991a. Duration of diapause in the stem borers, *Busseola fusca* and *Chilo partellus*. *Entomol. Exp. Appl.* 61: 265-270.

KFIR, R. 1991b. Selecting parasites for biological control of lepidopterous stalk borers in summer grain crops in South Africa. *Redia* 74: 231-236.

- KFIR, R.** 1992. Alternative, non-chemical control methods for the stalk borers, *Chilo partellus* (Swinhoe) and *Busseola fusca* (Fuller), in summer grain crops in South Africa. *Tech. Commun. Dep. Agric. Dev., Rep. S. Afr.* 232: 99-103.
- KFIR, R.** 1994. Attempts at biological control of the stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae), in South Africa. *Afr. Entomol.* 2: 67-68.
- KFIR, R.** 1995. Parasitoids of the African stem borer, *Busseola fusca* (Lepidoptera: Noctuidae), in South Africa. *Bull. Entomol. Res.* 85: 369-377.
- KFIR, R.** 1997a. Competitive displacement of *Busseola fusca* (Lepidoptera: Noctuidae) by *Chilo partellus* (Lepidoptera: Pyralidae). *Ann. Entomol. Soc. Am.* 90: 620-624.
- KFIR, R.** 1997b. Natural control of the cereal stemborers *Busseola fusca* and *Chilo partellus* in South Africa. *Insect Sci. Appl.* 17: 61-68.
- KFIR, R.** 1998. Maize and grain sorghum : southern Africa, pp. 333-347. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control.* CAB International. Wallingford, UK. 530 pp.
- KFIR, R.** 2001. Prospects for biological control of *Chilo partellus* in grain crops in South Africa. *Insect Sci. Appl.* 21: 275-280.
- KFIR, R. & BELL, R.** 1993. Intraseasonal changes in populations of the African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), in Natal, South Africa. *J. Afr. Zool.* 107: 543-553.
- KFIR, R., OVERHOLT, W.A., KHAN, Z.R. & POLASZEK, A.** 2001. Biology and management of economically important Lepidopteran Cereal Stem Borers in Africa. *Ann. Rev. Entomol.* 47: 701-731.

- LAHIFF, E.** 1997. Rural resources rural livelihoods working paper series: Land, water and local governance in South Africa: A case study of the Mutale River Valley. *Paper no. 7*. The economic and Social Research Council. Global environmental Change Programme Phase 3 project: *Dryland*
- LAWANI, S.M.** 1982. A review of the effects of various agronomic practices on cereal stem borer populations. *Trop. Pest Manag.* 28: 266-276.
- MAES, K.** 1997. The taxonomy of the Lepidopteran cereal stemborers of Africa. *Insect Sci. Appl.* 17: 9-12.
- MBAPILA, J.** 1994. Laboratory life tables of *Cotesia* spp. reared at different temperatures on *Chilo partellus*, 1994 *ICIPE Annual report*. ICIPE Science Press. 31 pp.
- MILLER, J.R. & COWLES, R.S.** 1990. Stimulo-deterrent diversion: a concept and its possible application to onion maggot control. *J. Chem. Ecol.* 16: 3197-3212.
- MILLER, J.C. & EHLER, L.E.** 1990. The concept of parasitoid guild and its relevance to biological control, pp. 159-169. In: Mackauer, M, Ehler, L.E. & Roland, J., eds. *Critical Issues in Biological Control*. Intercept, Andover, U.K. 330 pp.
- MOHYUDDIN, A.L.** 1971. Comparative biology and ecology of *Apanteles flavipes* (Cam.) and *A. sesamiae* (Cam.) as parasites of graminaceous borers. *Bull. Entomol. Res.* 61: 33-39.
- MOHYUDDIN, A.L.** 1972. Distribution, biology and ecology of *Dentichasmias busseolae* Heinr. (Hymenoptera: Ichneumonidae), a pupal parasite of graminaceous stem-borers (Lep., Pyralidae). *Bull. Entomol. Res.* 62: 161-168.
- MOHYUDDIN, A.L. & GREATHEAD, D.J.** 1970. An annotated list of the parasites of graminaceous stem borers in East Africa, with a discussion of their potential in biological control. *Entomophaga* 15: 241-274.

MURDOCH, W.W. 1975. Diversity, complexity, stability and pest control. *J. Appl. Ecol.* 12: 795-807.

NGI-SONG, A.J., OVERHOLT, W.A. & AYERTY, J.N. 1995. Suitability of African gramineous stemborers for development of *Cotesia flavipes* and *C. sesamiae* (Hymenoptera: Braconidae). *Environ. Entomol.* 24: 978-984.

NGI-SONG, A.J., OVERHOLT, W.A., NJAGI, P.G.N., DICKE, M., AYERTY, J.N. & LWANDE, W. 1996. Volatile infochemicals used in host and host habitat location by *Cotesia flavipes* (Cameron) and *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae), larval parasitoids of stemborers on gramineae. *J. Chem. Ecol.* 22: 307-323.

NUNES, E., SOUSA, D. & SATARIC, I. 1985. Research on the constraints to maize production in Mozambique. *To feed ourselves. Proc. First. East., Cent. South Afr. Reg. Maize Workshop.* Lusaka, Zambia.

NYE, I.W.R. 1960. The insect pests of graminaceous crops in East Africa. *Colonial Res. Stud.* Her Majesty's Stationary Off. London. 31: 48.

OMWEGA, C.O. & OVERHOLT, W.A. 1997. Progeny production and sex ratios of field populations of the parasitoids, *Cotesia flavipes* and *Cotesia sesamiae*, reared from gramineous stemborers in coastal Kenya. *Insect Sci. Appl.* 17: 137-142.

OVERHOLT, W.A. 1998. Biological control, pp. 349-363. In: Polaszek., A., ed. *Cereal stemborers in Africa: taxonomy, natural enemies, and control.* CAB International. Wallingford, UK. 530 pp.

OVERHOLT, W.A. & MAES, K.V.N. 2000. Field guide to the maize and sorghum stemborer larvae of eastern and southern Africa. ICIPE Science Press. Nairobi, Kenya.

OVERHOLT, W.A., NGI-SONG, A.J., KIMANI, S.W., MBAPILA, J., LAMMERS, J.P. & KIOKO, E. 1994. Ecological considerations of the introduction of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) for biological control of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae), in Africa. *Biocontr. News and Info.* 15: 19-24.

OVERHOLT, W.A., NGI-SONG, A.J., OMWEGA, C.O., KIMANI, S.W., MBAPILA, J., SALLAM, M.N. & OFOMATA, V. 1997. A review of the introduction and establishment of *Co. flavipes* (Cameron) in East Africa for biological control of cereal stemborers. *Insect Sci. Appl.* 17: 79-88.

OVERHOLT, W.A., OGEDAH, K. & LAMMERS P.M. 1994. Distribution and sampling of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in maize and sorghum on the Kenya coast. *ICRPE. Bull. Entomol. Res.* 84: 367-378.

POLASZEK, A. 1998b Bethylidae, 133-137. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control*. CAB International. Wallingford, UK. 530 pp.

POLASZEK, A., LA SALLE, J. & JONGEMA, Y. 1998. Chalcidoidea, 191-205. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control*. CAB International. Wallingford, UK. 530 pp.

POLASZEK, A. & WALKER, A.K. 1991. The *Cotesia flavipes* species-complex: Parasitoids of cereal stemborers in the tropics. *Redia* 74: 335-341.

POTTING, R.P.J. 1997. Evolutionary and applied aspects of the behavioural ecology of the stemborer parasitoid *Cotesia flavipes*. *Insect Sci. Appl.* 17: 109-118.

POTTING, R.P.J., OSAE-DANSO, F., OVERHOLT, W.A. & NGI-SONG, A.J. 1993. Host selection in *Cotesia flavipes*, parasitoid of tropical stemborers. *Proc. Exp. Appl. Entomol.* 4: 47-52.

RISCH, S.J., ANDOW, D. & ALTIERI, M.A. 1983. Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions. *Environ. Entomol.* 12: 625-629.

SALLAM, M.N., OVERHOLT, W.A. & KAIRU, E. 2002. Intraspecific and interspecific competition between *Cotesia flavipes* and *Cotesia sesamiae* (Hymenoptera: Braconidae), gregarious larval endoparasitoids of lepidopteran stemborers. *Biocontr. Sci. Tech.* 12: 493-506.

SCHULTESS, F., BOSQUE-PÉREZ, N.A. & GOUNOU, S. 1991. Sampling lepidopterous pests on maize in West Africa. *Bull. Entomol. Res.* 81: 297-301.

SESHU REDDY, K.V. 1983. Studies on the stem-borer complex of sorghum in Kenya. *Insect Sci. Appl.* 4: 3-10.

SESHU REDDY, K.V., LUBEGA, M.C. & SUM, K.O.S. 1990. Population patterns of *Chilo* spp. in sorghum, maize and millets. *Insect Sci. Appl.* 11: 549-554.

SITHOLE, S.Z. 1987. Maize insect pests in Zimbabwe. Toward Insect Resistant Maize for the Third World. *Proc. Int. Symp. Methodol. Developing Host Plant Resistance Maize Insects.* CIMMYT. Mexico: Mexico City. Pp. 286-88.

SITHOLE, S.Z. 1989. Sorghum stemborers in southern Africa. *International Workshop on Sorghum Stem Borers.* ICRISAT Sahelian Center, Niamey, Niger. India: Patancheru 502 324, Andra Pradesh, India: International Crop Research Institute for the Semi-Arid Tropics. Pp. 41-47.

SKOFGÅRD, H. & PÄTS, P. 1996. Effects of intercropping on maize stemborers and their natural enemies. *Bull. Entomol. Res.* 86: 599-607.

SMITH, J.W., JR. & WIEDENMANN, R.N. 1997. Foraging strategies of stemborer parasites and their application to biological control. *Insect. Sci. Appl.* 17: 37-49.

SMITH, J.W. JR, WIEDENMANN, R.N. & OVERHOLT, W.A. 1993. Parasites of Lepidopteran Stem-borers of Tropical Gramineous Plants. Nairobi: ICIPE. *Sci. Press.* 89 pp.

STERN, V.M., SMITH, R.F., VAN DEN BOSCH, R. & HAGEN, K.S. 1959. The integrated control concept. *Hilgardia* 29: 81-101.

SWAINE, C. 1957. The maize and sorghum stalkborer *Busseola fusca* (Fuller), in peasant agriculture in Tanganyika territory. *Bull. Entomol. Res.* 48: 711-722.

TAKASU, K. & OVERHOLT, W.A. 1997. Aggressive behaviour of *Chilo partellus* (Swinhoe) larvae against the parasitoid, *Cotesia flavipes* Cameron. *Insect Sci. Appl.* 17: 131-135.

TAMS, W.H.T. 1932. New species of African Heterocera. *Entomologist* 65: 1241-1249.

TAMS, W.H.T. & BOWDEN, J. 1953. A revision of the African species of *Sesamia* Guenee and related genera (Agrotidae-Lepidoptera). *Bull. Entomol. Res.* 43: 645-678.

TURLINGS, T.C.J., LOUGHRIN, J.H., MCCALL, P.J., RÓSE, U.S.R., LEWIS, W.J. & TUMLINSON, J.H. 1995. How caterpillar-damaged plants protect themselves by attracting parasitic wasps. *Proc. Natl. Acad. Sci. USA.* 92: 4169-4174.

VAN ACHTERBERG, C. & WALKER, A.K. 1998. Braconidae, pp. 137-187. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control*. CAB International. Wallingford, UK. 530 pp.

VAN DEN BERG, J. & DRINKWATER, T.W. 2000. Pink stem-borer. *Plant Protection series* no. 20. ARC Grain Crops Research Institute, Private Bag X1251, Potchefstroom, 2520, South Africa.

VAN DEN BERG, J. & EBENEKE, A.A. 2001. Integrated Management of Stem-borers in Lesotho. *Insect Sci. Appl.* 21: 389-394.

- VAN DEN BERG, J., NUR, A.F. & POLASZEK, A.** 1998. Cultural control, pp. 333-349. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control*. CAB International. Wallingford, UK. 530 pp.
- VAN DEN BERG, J., REBE, M., DE BRUYN, J. & VAN HAMBURG, H.** 2001. Developing habitat management systems for gramineous stemborers in South Africa. *Insect Sci. Appl.* 21: 381-388.
- VAN DEN BERG, J. & VAN RENSBURG, J.B.J.** 1991. Infestation and injury levels of stem borers in relation to yield potential of grain sorghum. *S. Afr. J. Plant Soil.* 8: 127-131.
- VAN DEN BERG, J., VAN RENSBURG, J.B.J. & PRINGLE, K.L.** 1990. Damage caused by *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) to various cultivars of grain sorghum, *Sorghum bicolor* (L.) Moench. *S. Afr. J. Plant Soil* 7: 192-196.
- VAN DEN BERG, J., VAN RENSBURG, J.B.J. & VAN DER WESTHUIZEN, M.C.** 1991. The effect of single and mixed populations of *Busseola fusca* (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) on damage to grain sorghum. *J. Entomol. Soc. sth. Afr.* 54: 231-242.
- VAN EMDEN, H.F. & WILLIAMS, G.** 1974. Insect stability and diversity in agro-ecosystems. *Ann. Rev. Entomol.* 19: 455-475.
- VAN HAMBURG, H.** 1980. The grain-sorghum stalk-borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae): survival and location of larvae at different infestation levels in plants of different ages. *J. Entomol. Soc. sth. Afr.* 43: 71-76.
- VAN HAMBURG, H.** 1987. A biological control approach to pest management on grain crops with special reference to the control of stalkborers. *Tech. Commun., Dep. Agric. Water Supply, Rep. S. Afr.* 212: 52-55.

VAN LEERDAM, M.B., SMITH, J.W., JR. & FUCHS, T.W. 1985. Frass mediated, host finding behaviour of *Cotesia flavipes* a braconid parasite of *Diatraea saccharalis* (Lepidoptera: Pyralidae). *Ann. Entomol. Soc. Amer.* 78: 647-650.

VAN RENSBURG, J.B.J. 1992. Evaluation of pheromone trapping systems in relation to light trap captures of the maize stalk borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *S. Afr. J. Plant Soil* 9: 144-149.

VAN RENSBURG, J.B.J. 1997. Seasonal moth flight activity of the maize stalkborer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in small farming areas of South Africa. *Appl. Plant Sci.* 11: 20-23.

VAN RENSBURG, G.D.J., & BATE, R. 1987. Preliminary studies on the relative abundance and distribution of the stalk borers *Busseola fusca* and *Chilo partellus*. *Tech. Commun., Dep. Agric. Water Supply, Rep. S. Afr.* 212: 49-52.

VAN RENSBURG, J.B.J. & VAN DEN BERG, J. 1992. Timing of insecticide application for stemborer control in maize and grain sorghum. *Appl. Plant Sci.* 6: 24-27.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1985. Geographical variation in the seasonal moth flight activity of the maize stalkborer, *Busseola fusca* (Fuller), in South Africa. *S. Afr. J. Plant Soil* 2: 123-126.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.M. 1987. Ecology of the stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *Bull. Entomol. Res.* 77: 255-269.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1988. Response of maize to levels and times of infestation by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *J. Entomol. Soc. sth. Afr.* 51: 283-291.

WALADDE, S.M., VAN DEN BERG, J., BOTLOHLE, P.M. & MLANJENI, N. 2001. Survey of maize stem borers in the Eastern Cape Province of South Africa. In: *Proceedings of the Final Workshop of the Southern African Stem Borer Management Programme. 2-5 July, 2001.* Pietermaritzburg, South Africa.

WALE, M. 1999. Population dynamics of the stemborers *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller) and *Sesamia calamistis* attacking sorghum in central Ethiopia. *Insect Sci. Appl.* 19: 149-156.

WALKER, P.T. 1981. The relation between infestation by lepidopterous stem borers and yield of maize: methods and results. *EPPO Bull.* 11: 101-106.

WIEDENMANN, R.N. & SMITH, J.W. 1993. Functional response of the parasite *Cotesia flavipes* (Hymenoptera: Braconidae) at low densities of the host *Diatraea saccharalis* (Lepidoptera: Pyralidae). *Environ. Entomol.* 22: 848-58.

WIEDENMANN, R.N. & SMITH, J.W. 1997. Novel associations and importation biological control: the need for ecological and physiological equivalencies. *Insect Sci. Appl.* 17: 51-60.

ZWART, K.W.R. 1998. Ichneumonidae. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control.* Wallingford, UK: CABI. 530 pp.

Table 1.1: Exotic and indigenous larval, pupal and egg parasitoids (Hymenoptera) identified in or introduced into South Africa. Parasitoids introduced for biological control are marked with a (#) symbol. Parasitoids marked with an asterisk include: indigenous larval parasitoids (*), pupal/larval parasitoids (***) and egg parasitoids (**).

Family	Parasitoid species	References	Year
Braconidae			
	<i>Tropobracon antennatus</i> (Granger)*	Van Achterberg & Walker	1998
	<i>Dolicho genidiaaethiopica</i> (Wilkinson) *	Van Achterberg & Walker	1998
	<i>Glyptapantelus maculitarsis</i> (Cameron) and <i>G. africanus</i> (Cameron) *	Van Achterberg & Walker	1998
	<i>Orgilus bifasciatus</i> (Turner) *	Van Achterberg & Walker	1998
	<i>Bassus sublevis</i> (Granger) *	Van Achterberg & Walker	1998
	<i>Iphiaulax dubiotus</i> (Shenefelt) *	Van Achterberg & Walker	1998
	<i>Parallorhogas pyralophagus</i> (Marsh)*	Van Achterberg & Walker	1998
	<i>Bracon sesamiae</i> (Cameron) *	Van Achterberg & Walker	1998
	<i>Allorhogas pyralophagus</i> (Marsh) *** #	Kfir	1994
	<i>Cotesia</i> spp.* 'complex': including <i>C. flavipes</i> (Cameron) #, <i>C. sesamiae</i> (Cameron), <i>C. ruficrus</i> (Haliday) and <i>C. chilonis</i> (Munakata) #	Van Achterberg & Walker Kfir	1998 1997b
Ichneumonidae			
	<i>Dentichasmias busseolae</i> (Heinrich) ***	Zwart	1998

	<i>Procerochasmias nigromaculatus</i> (Heinrich) ***	Zwart	1998
	<i>Syzeuctustonganus</i> (Kriechbaumer)***	Zwart	1998
	<i>Xanthopimpla stemmator</i> (Thunberg) *** #	Kfir	1997b
	<i>Mallochya pyralidis</i> (Wharton)***#	Kfir	1997b
	<i>Meloboris sinicus</i> (Holmgren)***#	Kfir	1997b
	<i>Holcopimpla concolor</i> (Brullé) ***	Zwart	1998
	<i>Pristomerus</i> sp. A*	Zwart	1998
	<i>Temelucha picta</i> (Holmgren) and <i>T. basiornata</i> (Cameron)*	Zwart	1998
	<i>Ichneumon rubriornatus</i> (Cameron) ***	Zwart	1998
	<i>Pimpla</i> sp. A ***	Zwart	1998
Bethylidae			
	<i>Odontepyrus transvaalensis</i> (De Buysson) *	Polaszek	1998b
Chalcidoidea (superfamily)			
	<i>Eurytoma braconidis</i> (Ferrière) ***	Polaszek, LaSalle & Jongema	1998
Trichogram- matidae (**)	<i>Trichogramma australicum</i> (Girault), <i>T. evanescens</i> Westwood), <i>T. chilonis</i> (Ishii), <i>T. ostriniae</i> (Pang & Chen)	Carnegie <i>et al.</i> Kfir	1985 1994
	<i>Trichogrammatoidea eldanae</i> (Viggiani)	Carnegie <i>et al.</i>	1985
	<i>Telenomus applanatus</i> (Bin & Johnson)	Carnegie <i>et al.</i>	1985
Eulophidae (***)	<i>Tetrastichus howardi</i> (Olliff) #	Kfir	1997b



Figure 1.1: Stemborer damage to a maize plant.



Figure 1.2: The Tshiombo irrigation scheme.



Figure 1.3: Pre- (left) and post-flowering (right) maize plants growing at Tshiombo.



Figure 1.4: Farmers (below) and technician (above) working at Tshiombo.

CHAPTER 2: Moth flight patterns of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae)

2.1 Introduction

Busseola fusca (Fuller) (Lepidoptera: Noctuidae) (Fig. 2.7) and *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) are important pests of maize that occur throughout sub-Saharan Africa (Ingram, 1983). *Busseola fusca* can reach economically important infestation levels throughout the production area but is of less importance at lower altitudes such as the Makatini flats (KwaZulu-Natal) and Eastern Cape (Van Rensburg, 1997). *Sesamia calamistis* is prevalent at low to medium altitudes especially in warmer coastal areas and the Lowveld with increasing importance inland, especially where irrigation is implemented (Van den Berg & Drinkwater, 2000).

The moth flight pattern of *B. fusca* has been studied well by Van Rensburg, Walters & Giliomee (1985) and Van Rensburg (1992, 1997). In commercial maize production systems, *B. fusca* moth flights commence during October and lasts until the first frost appears (mid-May) (Van Rensburg *et al.*, 1985). The *B. fusca* moth flight pattern is characterised by two and sometimes three distinct flight periods (Fig. 2.1). These moth flight patterns explain seasonal variation and allow an early warning system for possible stemborer outbreaks based on general planting date depending on the season and locality (Van Rensburg, 1997).

Geographical variation in the flight pattern of *B. fusca* was indicated to exist from the eastern to the western plateau of South-Africa's maize producing region. This variation has a significant impact on the magnitude of the second and third flights of *B. fusca* (Van Rensburg *et al.*, 1985). Third generation moth flights are not of significant importance in commercial maize farming systems on the Highveld region of South Africa due to the maize crop not being suitable for young larvae from early February onwards (Van Rensburg *et al.*, 1985).

The distinct moth flight patterns of *B. fusca* seem to be attributed to climatic variation in terms of magnitude and time (Van Rensburg *et al.*, 1985). The central plateau area of South Africa is

recognised for commercial maize production with a positive temperature and negative rainfall gradient from East to West. Moth flight patterns of a particular species may also vary between different localities (Robinson & Robinson, 1950) and observations have shown that for *B. fusca* it also differs between commercial and subsistence farms (Van Rensburg, 1997). In a study of *B. fusca* moth flight patterns in small-farming areas of South Africa, Van Rensburg (1997) observed significant variations in flight patterns between geographical areas and maize production systems. In commercial farming areas the first and second flights are separated by a period in December when no moths are recorded (Van Rensburg, 1997). High prevailing summer temperatures in the Limpopo Province resulted in second generation flights of *B. fusca*, which thus terminated in a third, unproductive seasonal flight that led to young larvae not being able to survive adverse conditions (Van Rensburg *et al.*, 1985). Rain appears not to restrict geographical distribution of moths but may have a pronounced effect on the seasonal abundance of *B. fusca* larvae (Van Rensburg *et al.*, 1985).

Moth flight patterns are often used to plan timing of chemical control actions against *B. fusca* (Van Rensburg, 1997). Although chemical control is not applied for stemborer control in small-farming systems in South Africa, knowledge of flight patterns is important for the development of integrated pest management systems where biological and cultural control strategies are used against these pests.

In the summer rainfall region of South Africa, *S. calamistis* infests maize stems during the first few weeks after crop emergence (October and November) and ears during February and March. The increasing numbers of irrigation systems in maize production may be responsible for the higher pest status of *S. calamistis*. These practices may lead to earlier availability of suitable host plants and the presence of volunteer maize for moths to oviposit on (Van den Berg & Drinkwater, 2000). *Sesamia calamistis* is becoming increasingly important especially in the interior part of South Africa. No information exists on *S. calamistis* moth flight patterns in South Africa.

The objectives of this study were to determine the moth flight patterns of *B. fusca* and *S. calamistis* in a sub-tropical maize production system where fields are irrigated and planting of maize is done continuously through the year.

2.2 Materials and Methods

Pheromone traps were used to monitor moth numbers over time. Monitoring was done from November 2004 until October 2006. The trapping site was located at the Tshiombo irrigation scheme (S22°47.863", E030°27.194", 635 m a.s.l.), north-east of Thohoyandou in the Limpopo Province. Approximately 930 plots, each 1.2 ha in size, make up the irrigation scheme at Tshiombo (Lahiff, 1997). Planting of maize is continuous and fields of different growth stages interspaced with large natural areas are characteristic of the small-farming system at the irrigation scheme.

Moths were trapped using omni-directional traps (Van Rensburg, 1992) (Fig. 2.6). Omni-directional trap designs are more effective than conventional delta traps for quantitative (moth abundance) moth population estimations (Van Rensburg, 1992). Female sex pheromone dispensers (*AgriSense*) containing slow-releasing synthetic *B. fusca* and *S. calamistis* sex pheromones were suspended from under the roof of each trap. For the first few months of this study *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) sex pheromones (*AgriSense*) were used but no moths were ever trapped, indicating that the *C. partellus* formulation was not effective.

Three traps for each species were mounted close to or in maize fields at the monitoring site. One trap each of *B. fusca* and *S. calamistis* were set up at the agricultural experimental station while others were in farmers' fields. Traps were positioned approximately 1 km apart with each trap being mounted on an upright pole 1.5 m above the ground. Traps were monitored at weekly intervals and when inspected, the trap receptacle was opened, number of moths recorded, removed, discarded and the receptacle replaced. Pheromone lures were replaced every four weeks except during the months of November 2005 until March 2006 when they were replaced every eight weeks. This was not expected to have a significant effect on moth catches since the recommended period between lure changes was six weeks. From April 2006 until October 2006 pheromone lures were again replaced every four weeks.

The mean number of moths trapped per week was calculated for each species. A 4-week running average was calculated for use in drawing of the general flight patterns.

2.3 Results and Discussion

The *B. fusca* (Fig. 2.7) flight pattern showed two distinct peaks, the first during during October and the second in late summer during December/January (Fig. 2.1). During 2005 periods existed when no *B. fusca* were trapped (Fig. 2.1). Periods of no moth flight activity occurred just prior to and after the second moth flight observed in December (2004). An extended period of zero or low *B. fusca* captures occurred during winter between May and end of August (2004/05) which may coincide with lower subtropical temperatures. During 2005/06 moth numbers started to increase from July. The fact that no moths were captured during winter months in 2004/05 could suggest diapause to occur as reported by Van Rensburg (1997). Van Rensburg (1997) observed a large number of *B. fusca* moths at Tshiombo during a study conducted between 1990/91 and 1993/94. Results reported by Van Rensburg (1997) corroborate this study which indicated that no clear separation of moth flight peaks is possible in small-farming areas. This is most likely due to planting date variation, which is typical of small-scale farming systems.

The moth flight patterns recorded by Van Rensburg *et al.* (1985) and Van Rensburg (1997) on the Highveld plateau region and the sub-tropical region of the Limpopo Province are presented in figures 2.3 and 2.4. In commercial farming systems characterised by uniform planting dates over a short period of time plants are normally lightly deposited on during September and no moths are recorded when light traps are used (Van Rensburg *et al.*, 1985).

During 2004/05 *B. fusca* numbers peaked during December but during 2005/06 the flight peaked a month later in January (Fig. 2.1). According to Van Rensburg (1997) the moth flight at Venda peaked at the start of November and at the start of December (Fig. 2.4). During December at Potchefstroom, which is typical of a large part of the commercial maize production area, definite periods of no moth activity were observed between the first and second and second and third moth flights of *B. fusca* (Van Rensburg, 1997). This moth flight pattern is largely stable and the times of peak flight activity do not deviate much over years (Fig. 2.3) (Van Rensburg *et al.*, 1985). Results of this study show that the moth flight pattern of *B. fusca* may differ between seasons.

Busseola fusca has the potential to attain important population levels in any climatic area and may increase in significance should maize become commercialised in areas traditionally used for small-scale farming (Van Rensburg *et al.*, 1985). Although no weather data or other environmental factors were included in this study, Van Rensburg (1997) indicated differences in both *B. fusca* moth abundance and temporal distribution could not be explained by variation in climatic factors, including differences in photoperiod between localities at different latitudes. The relatively high numbers of moths recorded at Tshiombo can be attributed to the absence of frost (Van Rensburg, 1997). Control of *B. fusca* in small-scale farming areas will be complicated compared to commercial systems in the Highveld region since the absence of clear generations and continuous presence and activity of moths will result in continuous infestation.

Sesamia calamistis moths (Fig. 2.9) were active from October to January and activity ceased during February (2004/05) (Fig. 2.2). Activity ceased at a later stage during the 2005/06 season from April onwards until the end of July. *Sesamia calamistis* was active during all winter months with higher numbers trapped during June and July (2004/05). In contrast, during 2005/06 no moths were recorded during this period. During the start of December and at the end of January increased numbers were observed indicating two peaks in moth activity (Fig. 2.2). During November (2004/05) *S. calamistis* moth flight activity was low compared to numbers during similar months of 2005/06 (Fig. 2.2). A second peak was also observed during late January in 2005/06 which contrasted with 2004/05 where numbers declined rapidly from late January until the end of March (Fig. 2.2).

Sesamia calamistis develops throughout the year with no diapause and may cause serious maize stand losses in maize production systems under irrigation in the Limpopo Province (Van den Berg & Drinkwater, 2000). It can be concluded that both *B. fusca* and *S. calamistis* were almost always present throughout the study period but no or very low levels of moth activity was observed during the period from January until September for *B. fusca* and February until April for *S. calamistis*.

Based on the abundance of moths, *B. fusca* is more significant than *S. calamistis*, but both species can attain economically important infestation levels, which may lead to a reduction in maize

yields. The numerous fluctuations in moth numbers and different flight periods make it difficult to implement efficient pest control strategies. However, the peaks shown especially for *B. fusca* (Fig. 2.1) can be a realistic estimate of possible stemborer infestation periods during the year (see Chapter 2).

Although no *C. partellus* moths (Fig. 2.8) were trapped, results on larval numbers indicate that *C. partellus* is the dominant stemborer species at this irrigation scheme. Studies on moth flight patterns of *C. partellus*, done by Van Hamburg (1979) in the semi-arid areas of the southern Limpopo Province, indicate that the moth flight patterns occurred during spring (between September – October) and late summer (February – April) (Fig. 2.5). Similarly, according to Bate, Van Rensburg & Giliomee (1990), at Potchefstroom, two main flight activity periods were observed, first from September – December and the second from January – May. These periods coincided with *B. fusca* and *S. calamistis* flight peaks at Tshiombo. According to Van Hamburg (1979) small numbers of *C. partellus* were caught during winter. With *C. partellus* moth flight patterns there is no clear distinction between different seasonal moth flight periods (Bate *et al.*, 1990). It can be ascribed to rapid population build-up and overlapping generations (Bate *et al.*, 1990).

It is important to note that both severity and time of occurrence of infestations in different localities are largely predetermined by the time of planting (Van Rensburg *et al.*, 1985). Fixed planting dates, like in the case of commercial, monoculture maize systems predetermine both severity and time of infestation at different localities. Planting dates that are fixed during spring time promote the occurrence of distinct generations of *B. fusca* later in the season. This is because these differences in abundance and temporal distribution of moths cannot be explained by climatic factors only, including photoperiods at different latitudes (Van Rensburg, 1997).

Timely release of egg and/or larval parasitoids of pests can only be made once information is available on the presence of the target life stages (Dent, 2001). Knowledge on the life history and bio-ecology of the pest species will help in planning timely releases of parasitoids based on the availability of sufficient pest numbers. Changing of planting dates to ensure that the susceptible stage of the crop does not coincide with periods of peak pest activity can also be based on moth

flight patterns (Van den Berg, Nur and Polaszek, 1998). Manipulation of planting date is recommended for *B. fusca* control on South African commercial farms due to moth absence for 2 – 4 weeks during first and second generation moth flights (Van Rensburg *et al.*, 1985). This changing of planting date may not be as successful on subsistence farming systems such as the sub-tropical areas where continuous planting of maize is done.

Adaptation of planting date for both *S. calamistis* and *B. fusca* to avoid maize being infested is not recommended in small-scale farming systems. Too many variations in flight patterns occur and the fact that irrigation is continuous provides for plants in the susceptible stages to be present throughout the year. If farmers were willing to adapt planting dates in order to escape serious *B. fusca* infestations, maize should not be planted during the latter half of November to the end of January. Irrigation is not a limiting factor at Tshiombo and due to water availability, planting dates may be manipulated especially when peaks are high during December – January.

More studies are needed at this irrigation scheme to gather information regarding moth flight patterns and how they are affected by environmental factors. Destructive sampling together with pheromone trapping may provide better understanding of the total ecology of maize stemborers.

2.4 References

- BATE, R., VAN RENSBURG, G.D.J. & GILIOME, J.H.** 1990. Moth flight pattern of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in the Western Transvaal. *J. Entomol. Soc. sth. Afr.* 53: 109-111.
- DENT, D.** 2001. Insect Pest Management. 2nd ed. CAB International. Wallingford, UK.
- INGRAM, W.R.** 1983. Biological control of graminaceous stemborers and legume podborers. *Insect Sci. Appl.* 4: 205-209.
- LAHIFF, E.** 1997. Rural resources rural livelihoods working paper series: Land, water and local governance in South Africa: A case study of the Mutale River Valley. *Paper no. 7*. The economic and Social Research Council. Global Environmental Change Programme, Phase 3 project: *Dryland*.
- ROBINSON, H.S. & ROBINSON, P.J.** 1950. Some notes on the observed behaviour of Lepidoptera in flight in the vicinity of light sources together with a description of a light trap designed to take entomological samples. *Int. Gaz.* 3.
- VAN DEN BERG, J., NUR, A.F. & POLASZEK, A.** 1998. Cultural control. In: Polaszek, A., ed. Cereal stemborers in Africa: Economic importance, Taxonomy, Natural enemies and Control. International Institute of Entomology. CAB International pp. 333-347.
- VAN DEN BERG, J. & DRINKWATER, T.W.** 2000. Pink stemborer. *Plant Prot. series no. 20*. ARC Grain Crops Research Institute, Private Bag X1251, Potchefstroom, 2520, South Africa.
- VAN HAMBURG, H.** 1979. The grain-sorghum stalk-borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae): seasonal changes in adult populations in grain sorghum in the Transvaal. *J. Entomol. Soc. sth. Afr.* 42: 1-9.

VAN RENSBURG, J.B.J. 1992. Evaluation of pheromone trapping systems in relation to light trap captures of the maize stalkborer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *S. Afr. J. Plant Soil* 9: 144-49.

VAN RENSBURG, J.B.J. 1997. Seasonal moth flight activity of the maize stalkborer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in small farming areas of South Africa. *Appl. Plant Sci.* 11: 20-23.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOME, J.H. 1985. Geographical variation in the seasonal moth flight activity of the maize stalkborer, *Busseola fusca* (Fuller), in South Africa. *S. Afr. J. Plant Soil* 2: 123-126.

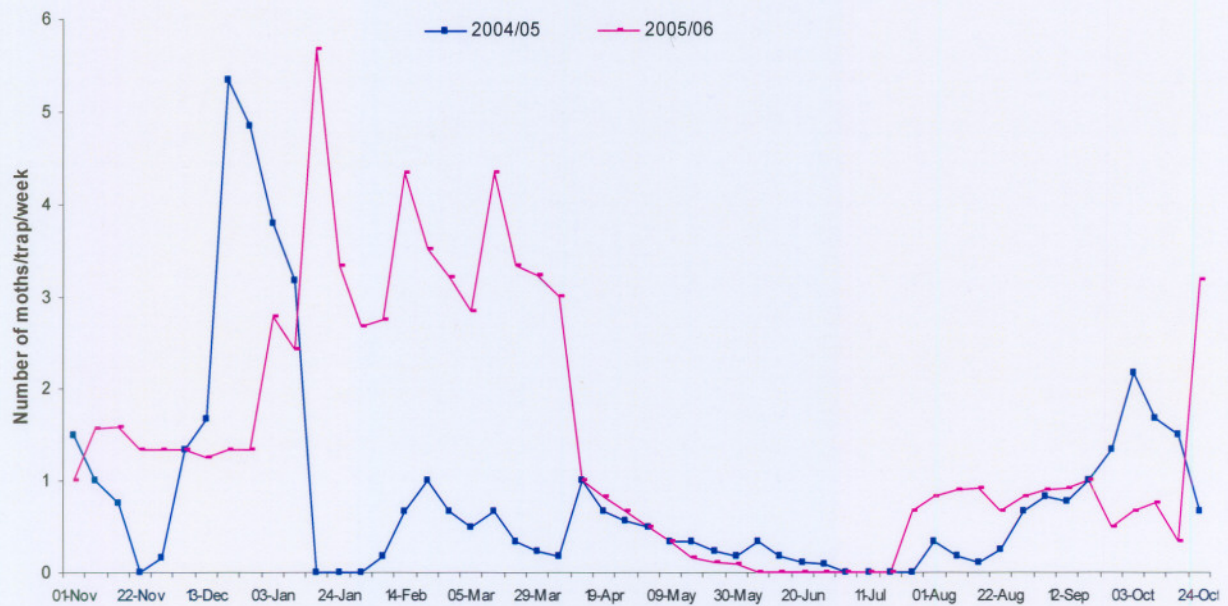


Figure 2.1: Average number of *Busseola fusca* moths per week caught in pheromone traps over the period 2004/05 and 2005/06 at the Tshiombo irrigation scheme.

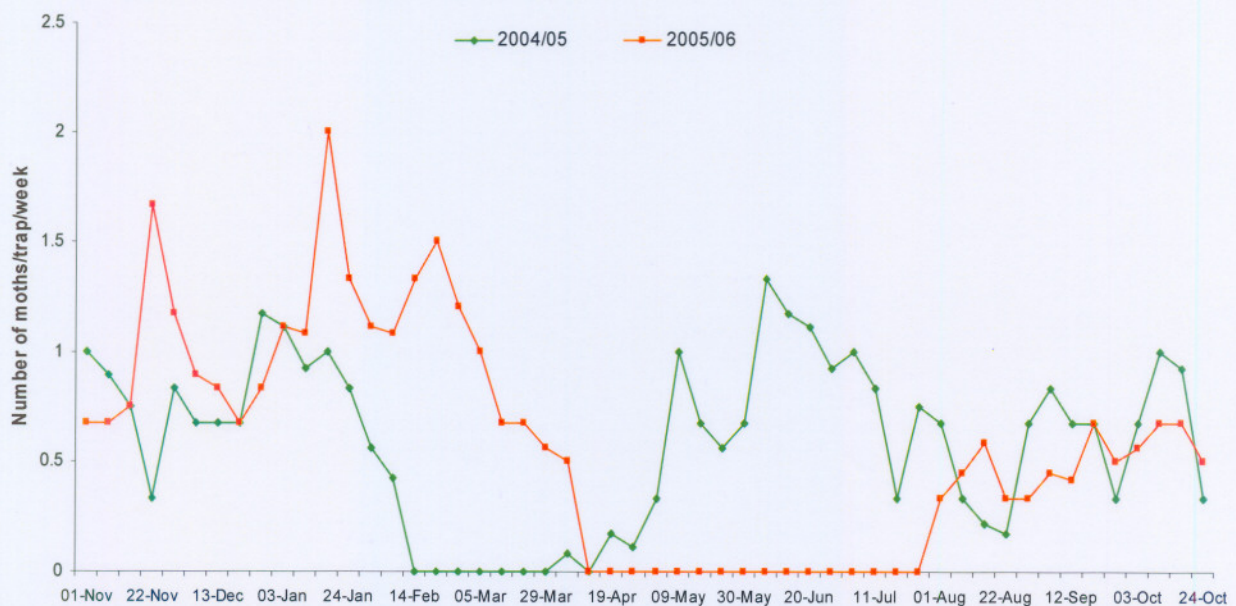


Figure 2.2: Average number of *Sesamia calamistis* moths per week caught in pheromone traps over the period 2004/05 and 2005/06 at the Tshiombo irrigation scheme.

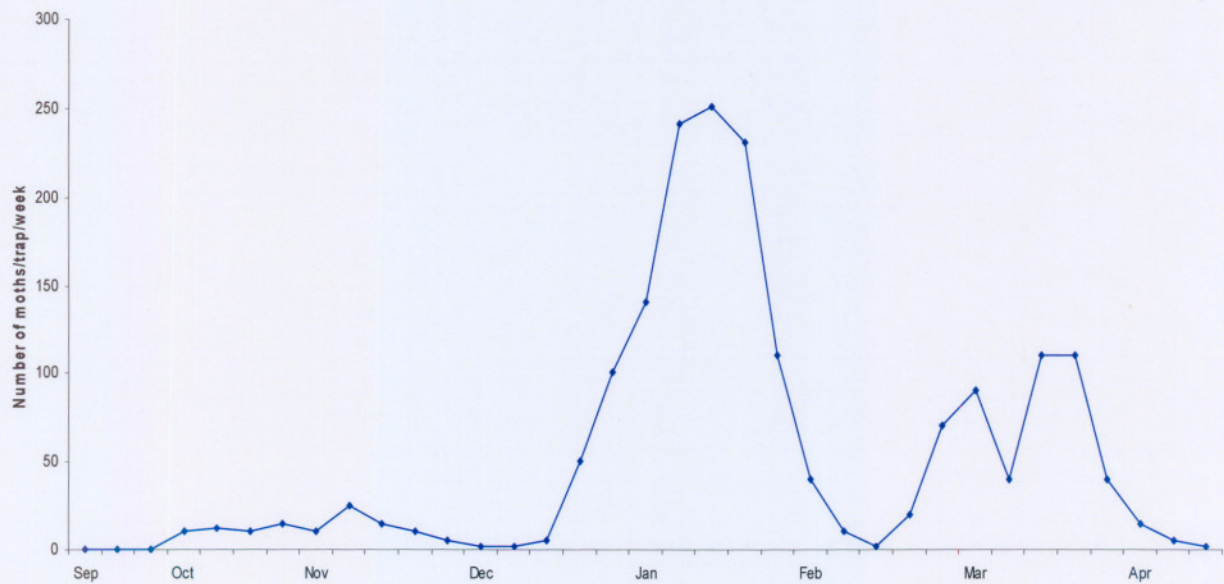


Figure 2.3: Total number of *Busseola fusca* moths per week caught with light traps at Potchefstroom during 1973/74 to 1975/76 (Van Rensburg, Walters & Giliomee, 1985).

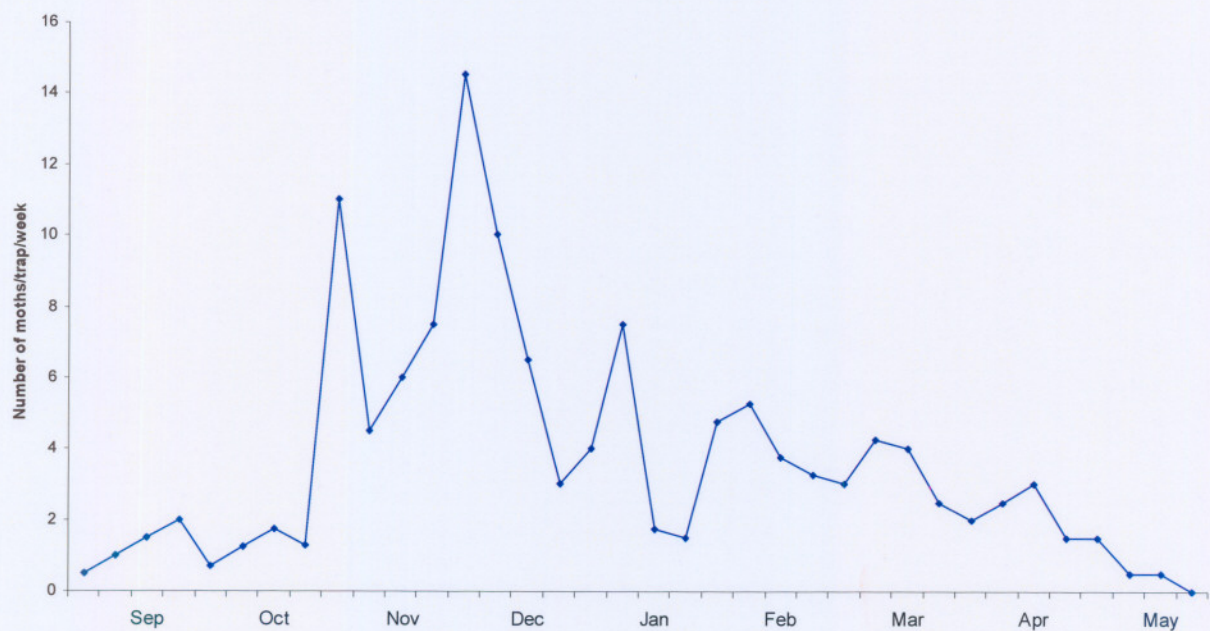


Figure 2.4: Average number of *Busseola fusca* moths per week caught in pheromone traps at Venda during 1990/91 to 1993/94 (Van Rensburg, 1997).

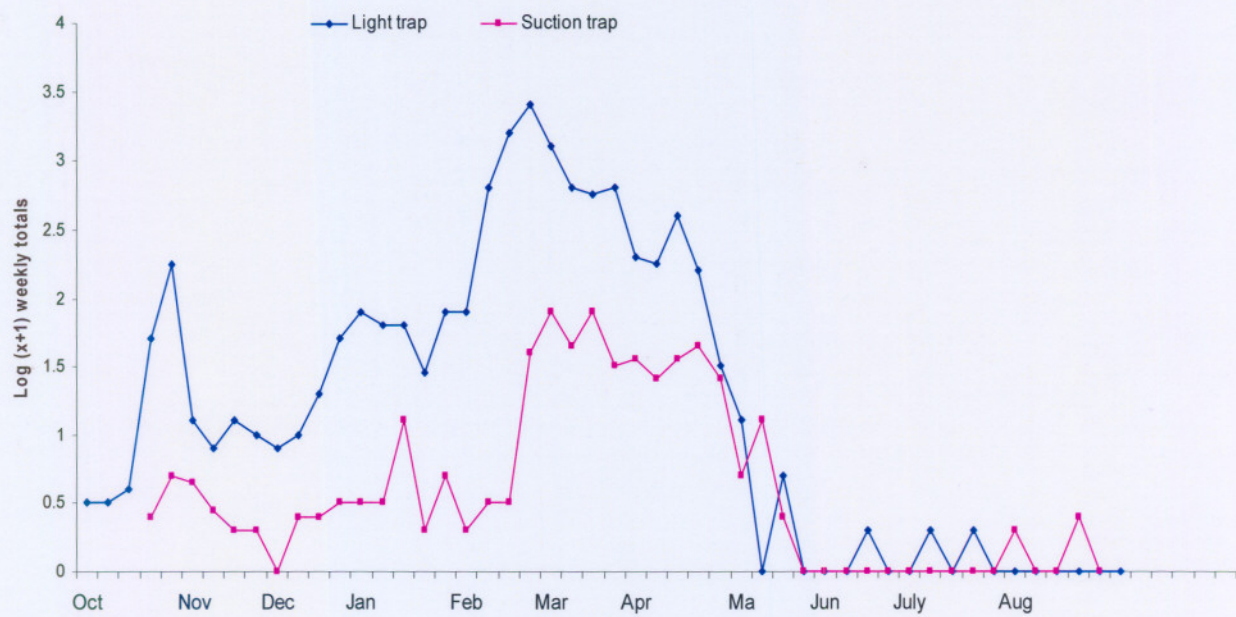


Figure 2.5: Weekly totals of adults of *Chilo partellus* caught in light and suction traps during the 1973/74 season in the northern Limpopo Province (Van Hamburg, 1979).



Figure 2.6: Omni-directional traps with pheromone lures used for capturing *Busseola fusca* and *Sesamia calamistis* moths.



Figure 2.7: *Busseola fusca* moth.



Figure 2.8: *Chilo partellus* moth.



Figure 2.9: *Sesamia calamistis* moth.

CHAPTER 3: The relative abundance of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) and their parasitoids

3.1 Introduction

Maize is an important resource in many small-scale farming areas in South Africa and prone to attack by three economically important stemborer species. These are *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) (Fig. 3.13), *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) (Fig. 3.14), and *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) (Fig. 3.15). Knowledge regarding the occurrence and biology of pests under local conditions is very important as information from other regions in Africa is often contradictory and not always applicable to South African conditions (Van Rensburg, Walters & Giliomee, 1987).

Busseola fusca occurs throughout the maize producing areas of South Africa, while *C. partellus* is reported to occur mostly in the arid northern and north-western parts of the country, the Lowveld region and in the northern parts of KwaZulu-Natal (Bate, Van Rensburg & Giliomee, 1991). *Chilo partellus* does not occur in the eastern Highveld region of South Africa (Bate *et al.*, 1991), although it is probably a matter of time before this area is invaded, as it is an effective coloniser capable of displacing *B. fusca* (Kfir, 1997). *Sesamia calamistis* is widespread throughout sub-Saharan Africa (Annecke & Moran, 1982) and is becoming increasingly important in the North-West- and Limpopo Provinces of South Africa, especially where irrigation is implemented (Van den Berg & Drinkwater, 2000).

Chilo partellus has a competitive advantage over *B. fusca* (Kfir, 1997) due to a three-week shorter development time in the life cycle of *C. partellus*. *Sesamia calamistis* is the least important of the three stemborer species and infestation levels in maize always seem to be low. *Sesamia calamistis* is normally kept under control by parasitoids in southern Africa (Kfir, 1998) and field surveys in Mozambique showed that although *S. calamistis* occurred at all elevations, infestation levels were low (Cugala & Omwega, 2001). According to Wale (1999), *S. calamistis*

makes up less than 1 % of the stemborer population in Ethiopia followed by *C. partellus* (92 %) and *B. fusca* (7.7 %).

Cotesia sesamiae (Cameron) (Hymenoptera: Braconidae) (Fig. 3.16) is the most common larval parasitoid of stemborers in sub-Saharan Africa (Omwega & Overholt, 1997). This gregarious larval endoparasitoid is indigenous to many regions in Africa where it attacks a wide range of stemborer hosts (Polaszek & Walker, 1991) and shares a common evolutionary history with several other native stemborers (Mohyuddin, 1971). *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae), also a gregarious larval endoparasitoid, is indigenous to south and southeast Asia (Polaszek & Walker, 1991) where it is recorded as a natural enemy of *C. partellus* (Polaszek & Walker, 1991; Mohyuddin, 1971). *Cotesia flavipes* was introduced into South Africa from Pakistan and released in large numbers in stemborer infested maize fields in e.g. Limpopo Province and KwaZulu-Natal (Kfir, 1998). Parasitism levels of *C. partellus* can be high. Kfir (1992a) observed *C. partellus* parasitism levels of 60 – 70 % by the parasitoid complex of *Co. sesamiae* and other larval parasitoids such as the solitary ectoparasite, *Euvipio* sp. (Braconidae). The most abundant larval parasitoid at many sites in South Africa is *Co. sesamiae* which is active throughout the season. This parasitoid species was reared from 93 % of all parasitized larvae at one site (Kfir, 1990). In KwaZulu-Natal, Kfir & Bell (1993) also recorded a high incidence of larval parasitism mainly by *Co. sesamiae*, which was reared from 87 % of parasitized *B. fusca* larvae.

No information is available on the ecology of stemborers and their parasitoids in subsistence farming systems in South Africa. The objective of this study was to study the relative abundance of stemborers and their natural enemies at the Tshiombo irrigation scheme. This will provide information on species distribution and population dynamics as well as which parasitoids occur in this region.

3.2 Materials and Methods

The study was done at the Tshiombo irrigation scheme (S22°47.863", E030°27.194", 635 m a.s.l.), north-east of Thohoyandou in the Limpopo Province. This scheme consists of

approximately 930 plots, each 1.2 ha in size (Lahiff, 1997). On this irrigation scheme, farmers have expanded the range of crops grown, extended the growing season, and generally intensified production compared to rain-fed farming systems in the region (Lahiff, 1997). Planting of maize is continuous and fields with crops at different growth stages interspaced with large natural areas are characteristic of the small-farming system at the irrigation scheme. Crop rotation is done with crops such as sweet potatoes, groundnut, 'muxe' (a traditional crop), cabbage and tomato.

3.2.1 Assessment of the incidence of damaged plants

The incidence of stemborer damaged plants was monitored on farmers' fields between June 2005 and March 2006 (Fig. 3.12). Assessments were done every four to six weeks and coincided with data collection on stemborer species distribution. The number of stemborer infested plants was determined on five different fields during the pre-flowering and five different fields during the post-flowering stages of crop development at each sampling date. The two groups of plants (pre-flowering and post-flowering) were sampled at each date. Pre-flowering plants were between four and six weeks old while post-flowering plants were between the flowering and soft dough stages.

The incidence of stemborer damaged plants was monitored on 5 – 10 farms over the irrigation scheme at each sampling date. On each field eight randomly selected plots (replicates) were investigated for stemborer damage. Plant stand and the number of plants exhibiting stemborer damage symptoms were determined in each replicate. Each replicate consisted of a row of between 16 – 20 plants. Maize is planted in short rows on ridges at this irrigation scheme to facilitate the flood irrigation system that is still managed by hand. The incidence of stemborer infested plants was expressed as a percentage of the plant stand per plot and the mean determined for each field.

3.2.2 Stemborer species distribution

Sampling of stemborer damaged plants was done every four to six weeks, starting October 2004 until March 2006 (Fig. 3.12). Between 50 and 100 stemborer damaged plants of the two age

groups (pre- and post-flowering) were dissected at each sampling date. Between 5 to 10 damaged plants were randomly collected from different fields for dissection.

Maize plants were dissected and stemborer larvae were collected and individually transferred to cut maize stems inside petri dishes for determination of parasitism levels. Larvae were identified and classified according to size: small, medium and large. Small larvae (first and second instars) were not collected, but numbers were recorded. These small larvae were identified according to their characteristic colour and marks on body segments. Since larval parasitoids do not necessarily parasitize 1st and 2nd instar larvae, their numbers were not taken into account in calculation of parasitism levels.

Each petri dish was labelled to indicate the sample number and whether it were larvae, pupae (dead or alive but identifiable as a stemborer), parasitized larvae (blackening or black spots on larvae were considered an indication of parasitism) and parasitized pupae (blackening of pupae). The sample number was marked on the lid of each petri dish. All petri dishes were fastened with masking tape and arranged in plastic containers and cooler boxes to maintain darkness, moisture and cleanliness for removal to the laboratory.

Stemborers were kept at 25° C (\pm 1° C) in an incubator to continue the rearing process. Larvae were checked every three to four days during which food was replaced and any emergence of moths / parasitoids recorded. Newly-emerged moths were killed using ethyl acetate after which they were pinned and preserved. Larval parasitoids were preserved dry in empty gelatine capsules. Pupal parasitoids were pinned and preserved. Parasitoids were identified at the National Collection of Insects, Biosystematics Division, ARC – Plant Protection Research Institute (Pretoria, South Africa).

3.3 Results

During the 15-month sampling period a total of 2413 larvae was collected which were reared through to adults. Three species, *B. fusca*, *C. partellus* and *S. calamistis* were recorded in mixed populations. *Chilo partellus* was the most dominant species all-year round, reaching proportions

of more than 95 % of the total population at certain sampling dates which included April and November (2005) and January and March (2006) (Fig. 3.1). *Chilo partellus* represented more than 80 % of the total stemborer population during all months except during the winter months of June and August when it made up between 65 – 68 %. *Busseola fusca* made up between 0 – 16 % of the population at different sampling dates while *S. calamistis* made up between 0 – 31 % (Fig. 3.1). *Sesamia calamistis* made up a high proportion of the population only during August and February while *B. fusca* was only present in significant numbers during January and June (Fig. 3.1).

On young plants the mean numbers of *B. fusca* larvae ranged between 0 and 0.65 (\pm SE 0.07) / plant (Fig. 3.2). Two peaks in larval numbers were observed, the first during January and the second during June. Larval numbers were very low during winter months with levels of < 0.1 larvae / plant (Fig. 3.2). Larval numbers were considerably higher during the 2004/05 period than the 2005/06 period. *Busseola fusca* larval numbers on plants during post-flowering stages ranged between 0 and 0.5 (\pm SE 0.07) larvae / plant (Fig. 3.3). Two peaks in larval numbers were also observed on older plants with the first during October and again in June (Fig. 3.3). These peaks were, however, only observed during 2004/05. No *B. fusca* larvae were recovered from any plants sampled during the post-flowering stage in 2005/06.

On young plants the mean numbers of *S. calamistis* larvae ranged between 0 and 1.72 (\pm SE 0.09) / plant (Fig. 3.4). A peak in larval numbers was observed during August. Larval numbers were very low in the majority of months with levels of < 0.4 larvae / plant (Fig. 3.4). *Sesamia calamistis* numbers on plants during post-flowering stages ranged between 0 and 0.74 (\pm SE 0.11) / plant (Fig. 3.5). Three peaks in larval numbers were observed on older plants during the year with the first occurring during October, the second in May and the third during August. Larval numbers over time during the 2004/05 period was similar to the 2005/06 period with numbers less than 0.35 larvae / plant (Fig. 3.5). Larval numbers were low during the period between November – January and again in July.

On young plants the mean numbers of *C. partellus* larvae were high and ranged between 0.26 and 4.20 (\pm SE 0.50) / plant (Fig. 3.6). Two peaks in larval numbers were observed, the first during

January and the second during August (Fig. 3.6). On post-flowering plants *C. partellus* ranged between 0 and 2.97 (\pm SE 0.25) / plant (Fig. 3.7). Two peaks in larval numbers were also observed on older plants with the first occurring during November and again in March (Fig. 3.7).

The incidence of plants exhibiting damage symptoms in whorls ranged between 7 and 30 % during the period from June 2005 to March 2006. There was a tendency of increased numbers of damaged plants during the period from July to February on fields in the pre-flowering stages (Fig. 3.6) and June and November during the post-flowering stage (Fig. 3.7).

All life stages of *C. partellus* were found throughout the year (Fig. 3.8). No *C. partellus* moths were caught at Tshiombo because of the pheromone being ineffective (Chapter 2). A study by Van Hamburg (1979) showed that the moth flight pattern of *C. partellus* in the semi-arid areas of the southern Limpopo Province indicated that peaks in moth flight activity occurred during spring (between September – October) and late summer (February – April). These patterns coincide with larval numbers found at Tshiombo during both growth stages. Small larvae of *B. fusca* were not recorded in November, April and January and an irregular pattern in the different cohorts was observed over time (Fig. 3.9). In some months no *B. fusca* larvae were collected from plants. The distribution of different life stages of *S. calamistis* also exhibited an erratic pattern over time (Fig. 3.10). Small larvae were absent or only recorded in very low numbers during the summer months of November – March. Both *B. fusca* and *S. calamistis* moths were almost always present throughout the study but no or very low levels of moth activity was observed from January – September for *B. fusca* and February until April for *S. calamistis* (Chapter 2).

The average total larval parasitism for all species was 10 % over the study period. For *C. partellus* the average parasitism level ranged between 0 – 34 % with an average of 8 % (Fig. 3.11). Parasitism levels for *B. fusca* ranged between 0 – 7 % with an average of 1 % and for *S. calamistis* parasitism was 0 – 3 % with an average of 0.5 %. The only larval parasitoid that was recorded was *Co. sesamiae* which was reared from *B. fusca*, *S. calamistis* and *C. partellus*. The only pupal parasitoid was *Dentichasmias busseolae* (Heinrich) (Hymenoptera: Ichneumonidae) (Fig. 3.17) (6 individuals) which was reared from *B. fusca* and *C. partellus*.

Parasitism levels of *C. partellus* were highest during February 2005 and January 2006 while that for *S. calamistis* and *B. fusca* were highest during July and February, respectively (Fig. 3.11).

3.4 Discussion

Busseola fusca, *S. calamistis* and *C. partellus* were observed in mixed populations in the same planting as well as in individual plants. Similar observations were made by Bate, Van Rensburg & Giliomee, (1991) and Van Rensburg, Walters & Giliomee (1988) in the Highveld region of South Africa. *Chilo partellus* can be considered the most important species at Tshiombo since it made up between 75 – 99 % of the total stemborer population over the whole sampling period. All larval stages of *C. partellus* were present throughout the year, which indicated that conditions were always suitable for larval development. In the Highveld region of South Africa, where winter temperatures decrease to levels that are not suitable for larval development, no stemborer activity is noticed during the winter months (Annecke & Moran, 1982; Van Hamburg, 1987) and moth activity only commences after larval diapause is terminated (Van Rensburg, Walters & Giliomee, 1985; 1987). Contrary to the pattern of zero *B. fusca* activity observed in commercial maize production systems in the western and eastern maize producing areas of South Africa (Van Rensburg, Walters & Giliomee, 1985), *B. fusca* activity was noticed throughout the year and especially during the winter months. A combination of temperature and photoperiod during winter could have played a significant role in the termination of diapause by *B. fusca* (Kfir, 1993). The high incidence of stemborer infestation and activity throughout the year is ascribed to the continuous planting of maize, which is made possible by irrigation at Tshiombo.

Although Kfir (1997) speculated that *B. fusca* tends to avoid plants which were previously infested by *C. partellus*, both species were often recorded on the same plant in this study. During the pre- and post-flowering stages *B. fusca* larval numbers were below 1 / plant. The increased larval infestation levels observed during January (young plants) (Fig. 3.2) fall within the main maize producing period at Tshiombo. This peak in *B. fusca* larval numbers on pre-flowering plants coincided with increased moth catches during January (Chapter 2). Another peak in larval numbers was observed during June in both young (Fig. 3.2) and old (Fig. 3.3) maize plants. Larval numbers were lower during 2005/06 than the previous period in 2004/05.

During the pre- and post-flowering stages *S. calamistis* had a high of 1.72 and 0.74 larvae / plant, respectively. Larval numbers on plants during the post-flowering stage were low during the period between November – January and again in July. *Sesamia calamistis* numbers only peaked during August on young plants but three peaks were observed during October, May and August, respectively, on older plants. *Sesamia calamistis* development normally slows down during winter but peaks occurring during May and August could suggest potential larval outbreaks in future as these peaks do not coincide with *C. partellus* and *B. fusca* peaks. The pattern of larval numbers over time during the 2004/05 and 2005/06 periods was similar. Compared to reports on *S. calamistis* in other areas of South Africa, *S. calamistis* numbers were relatively high and it made up a significant proportion of the population during certain months.

Chilo partellus infestation levels were high compared to the other stemborer species. Infestation levels of as high as 4.20 larvae / plant were observed during the pre-flowering stage and 2.97 larvae / plant during the post-flowering stage. These infestation levels are relatively similar to those observed by Kfir (1992b) in a more arid production area. He recorded infestation levels of 3 larvae / plant with peak infestations during February. On young plants increased larval infestation levels were observed during January and August. On old plants larval numbers peaked during March and November. Continuous planting of maize throughout the year with continuous irrigation and warm subtropical conditions may explain why larval infestations were relatively high (up to 4.20 larvae / plant) at Tshiombo.

The incidence of damaged plants (Fig. 3.6) ranged between 7 – 30 % per field and was above 10 % for most of the period. *Busseola fusca* numbers at Tshiombo were negligible and whorl damage symptoms can largely be ascribed to *C. partellus*. In a study conducted on *C. partellus* in Potchefstroom, the level of whorl damage two weeks after infestation proved reliable for the estimation of yield losses. The economic threshold was determined as 40 % plants with visible whorl damage (Bate & Van Rensburg, 1992). The infestation levels of *C. partellus* at Tshiombo can therefore be considered to be relatively low and possibly not of economic importance. Seshu-Reddy & Sum (1992) determined economic injury levels (EIL) for *C. partellus* on three varieties of maize by infesting plants at four different ages with newly hatched larvae. They found that the EIL ranged between 0.66 – 1.41 larvae / plant depending on variety and plant age at time of

infestation. In contrast, this level is much lower than the 2.97 and 4.20 larvae / plant on young and older plants, respectively, at Tshiombo. This low visual damage and high larval infestations especially for *C. partellus* show that visual symptoms of stemborer damage are not always the best predictor of larval infestations. The generally low stemborer infestation levels observed at Tshiombo could possibly be ascribed to crop rotation and cultivation of soil which destroys nearly all plant residues which could harbour stemborers.

The presence of small and medium-sized larvae (Fig. 3.8) of *C. partellus* indicated that it developed throughout the year and that there is no period when *C. partellus* does not infest plants at Tshiombo. Small and medium-sized larvae of *B. fusca* and *S. calamistis* were present in very low numbers and even absent during certain periods between October and March. This indicates that *B. fusca* populations could have gone into diapause and that *S. calamistis* development was slowed down during this period. In contrast to *B. fusca*, *S. calamistis* develops throughout the year and has no resting stage (Harris, 1962).

Large larvae of *B. fusca* and *C. partellus* may have entered obligatory diapause and quiescence respectively when the maize crop matured (Kfir, 1991; 2000) or might have been attacked by predators such as ants or might have been washed away by rain. The fluctuation in stemborer numbers was synchronised with the size distribution. An increase in the proportion of young larvae (small and medium larvae) resulted in an increase in the incidence of infestation.

An integrated pest management approach may be sufficient to reduce pest populations and crop damage to below economic threshold levels in South Africa (Kfir 1990). More studies are needed especially regarding damage potential in terms of yield loss to determine economic threshold levels (ETLs) for all three species in mixed populations. Due to the large proportions of small and medium larvae found at Tshiombo and the fact that up to 81 % of *B. fusca* larvae up to the fourth instar were found in the whorl (Van Rensburg & Bate, 1987), a granular insecticide formulation will be the most appropriate chemical control method to reduce stemborer numbers.

Larval parasitoids were active all-year round. The most abundant parasitoid was *Co. sesamiae* which was reared from 85 % of parasitized larvae. *Cotesia sesamiae* parasitized all three

stemborer species with the mean level of parasitism being 10 % over the study period (Fig. 3.11). The highest parasitism level observed was on *C. partellus* larvae (34 %) during January but an average of only 8 % was observed with this species. The mean level of parasitism of *S. calamistis* and *B. fusca* was below 1%. The percentage parasitism was higher on *C. partellus* during 2005/06 than the previous period during 2004/05. The peak in larval parasitism coincided with the peak in the *C. partellus* larval population during January on plants in the pre-flowering period. During January 2005/06 the *Co. sesamiae* parasitism level peaked on *C. partellus* (34 %). In winter parasitism levels were not much lower than in other seasons. Kfir (1990) also observed that *C. sesamiae* was the most abundant parasitoid of *C. partellus* when it was reared from 93 % of parasitized larvae at Brits in the North-West Province. At Delmas and Cedara parasitoids were recorded from *B. fusca* with *Co. sesamiae* being the most abundant parasitoid (Kfir, 1995). In both the Highveld region and KwaZulu-Natal *Co. sesamiae* was active throughout the season on *B. fusca* (Kfir, 1997) especially during March in KwaZulu-Natal when larval parasitism of between 60 – 75 % was observed (Kfir & Bell, 1993).

Cotesia sesamiae and *Co. flavipes* are ecologically similar parasitoids that attack medium to large-sized larvae (Smith, Wiedenmann & Overholt, 1993). *Cotesia sesamiae* attacks all three stemborer species (Kfir & Bell, 1993; Mohyuddin & Greathead, 1970) as was also observed at Tshiombo. The presence of *C. partellus* throughout the year and successful biological control using the exotic larval parasitoid *Co. flavipes* against *C. partellus* makes this braconid an ideal candidate for release in the Tshiombo area. In a study in Kenya *Co. flavipes* was observed to have higher searching ability and attacked more larvae than *Co. sesamiae* (Sallam, Overholt & Kairu, 1999). *Cotesia flavipes* also out-competed *Co. sesamiae* when *C. partellus* was parasitized by both species (Sallam, Overholt & Karui, 1999). *Cotesia flavipes* has a wide host range and attacks stemborers in large-stemmed grasses like maize (Kfir, Overholt, Khan & Polaszek, 2001). The only successful biocontrol attempt with *Co. sesamiae* was with its introduction from mainland Africa to the Indian Ocean islands against *S. calamistis* in maize (Kfir *et al.*, 2001). *Cotesia flavipes* may supplement indigenous parasitoids in population regulation and makes an ideal candidate for biological control. The number of failures to establish *Co. flavipes* against an old-association host, *C. partellus*, in mainland Africa can be due to competition with *Co. sesamiae* since the two species are not able to co-exist. Wiedenmann & Smith (1993)

demonstrated that, even at low densities, *Co. flavipes* was able to successfully locate stemborer hosts.

The pupal parasitoid *D. busseolae* was recovered in very low numbers and only from *C. partellus* and *B. fusca*. These low numbers at Tshiombo (six specimens) are in contrast to observations made by Kfir (1992b) at Brits in the North-West Province. At the latter site, pupal parasitism by *D. busseolae* on *C. partellus* contributed significantly and reached 100 % in many seasons.

Biological control on its own may not reduce stemborer populations, especially in the highveld region and KwaZulu-Natal where parasitoid establishment is poor according to South African reports (Kfir 1997). Trap cropping with Napier grass (Chapter 4) may also reduce stemborer numbers under certain conditions. These technologies may be integrated in a sustainable pest management programme to facilitate the control of cereal stemborers especially in mixed populations.

3.5 References

- ANNECKE, D.P. & MORAN, V.C. 1982. Insects and mites of cultivated plants in South Africa. Durban, South Africa, Butterworths. 383 pp.
- BATE, R. & VAN RENSBURG, J.B.J. 1992. Predictive estimation of maize yield loss caused by *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in maize. *S. Afr. J. Plant Soil* 9: 150-154.
- BATE, R., VAN RENSBURG, G.D.J. & GILIOMEE, J.H. 1991. Distribution and occurrence of the stem-borer *Chilo partellus* (Swinhoe) (Pyralidae) on maize in South Africa. *J. Afr. Zool.* 105: 11-15.
- CUGALA, D. & OMWEGA, C.O. 2001. Cereal stemborer distribution and abundance, and introduction and establishment of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) in Mozambique. *Insect Sci. Appl.* 21: 281-287.
- HARRIS, K.M. 1962. Lepidopterous stem borers of cereals in Nigeria. *Bull. Entomol. Res.* 53: 139-171.
- KFIR, R. 1990. Parasites of the spotted stalk borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in South Africa. *Entomophaga* 35: 403-410.
- KFIR, R. 1991. Duration of diapause in the stemborers, *Busseola fusca* and *Chilo partellus*. *Entomol. Exp. Appl.* 61: 265-270.
- KFIR, R. 1992a. Alternative, non-chemical control methods for the stalk borers, *Chilo partellus* (Swinhoe) and *Busseola fusca* (Fuller), in summer grain crops in South Africa. *Tech. Commun. Dep. Agric. Dev., Rep. S. Afr.* 232: 99-103.
- KFIR, R. 1992b. Seasonal abundance of the stemborer *Chilo partellus* (Lepidoptera: Pyralidae) and its parasites on summer grain crops. *J. Econ. Entomol.* 85: 519-529.

KFIR, R. 1993. Diapause termination in *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in the laboratory. *Ann. Entomol. Soc. Am.* 86: 273-277.

KFIR, R. 1995. Parasitoids of the African stemborer, *Busseola fusca* (Lepidoptera: Noctuidae), in South Africa. *Bull. Entomol. Res.* 85: 369-377.

KFIR, R. 1997. Competitive displacement of *Busseola fusca* (Lepidoptera: Noctuidae) by *Chilo partellus* (Lepidoptera: Pyralidae). *Ann. Entomol. Soc. Am.* 90: 620-624.

KFIR, R. 1998. Maize and grain sorghum: southern Africa. In: Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control*. Wallingford, UK: CABI. 530 pp.

KFIR, R. 2000. Seasonal occurrence, parasitoids and pathogens of the African stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), on cereal crops in South Africa. *Afr. Entomol.* 8: 1-14.

KFIR, R. & BELL, R. 1993. Intraseasonal changes in populations of the African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), in Natal, South Africa. *J. Afr. Zool.* 107: 543-553.

KFIR, R, OVERHOLT, W.A., KHAN, Z.R. & POLASZEK, A. 2001. Biology and management of economically important lepidopteran cereal stemborers in Africa. *Ann. Rev. Entomol.* 47: 701-731.

LAHIFF, E. 1997. Rural resources rural livelihoods working paper series: Land, water and local governance in South Africa: A case study of the Mutale River Valley. *Paper no. 7*. The economic and Social Research Council. Global environmental Change Programme Phase 3 project: *Dryland*.

MOHYUDDIN, A.L. 1971. Comparative biology and ecology of *Apanteles flavipes* (Cam.) and *A. sesamiae* (Cam.) as parasites of graminaceous borers. *Bull. Entomol. Res.* 61: 33-39.

MOHYUDDIN, A.I. & GREATHEAD, D.J. 1970. An annotated list of the parasites of graminaceous stemborers in East Africa, with a discussion of their potential in biological control. *Entomophaga* 15: 241-274.

OMWEGA, C.O. & OVERHOLT, W.A. 1997. Progeny production and sex ratios of field populations of the parasitoids *Cotesia flavipes* and *Cotesia sesamiae* reared from gramineous stemborers in coastal Kenya. *Insect Sci. Appl.* 17: 137-142.

POLASZEK, A. & WALKER, A.K. 1991. The *Cotesia flavipes* species-complex: Parasitoids of cereal stemborers in the tropics. *Redia* 74: 335-341.

SALLAM, M.N., OVERHOLT, W.A. & KAIRU, E. 1999. Comparative evaluation of *Cotesia flavipes* and *C. sesamiae* (Hymenoptera: Braconidae) for the management of *Chilo partellus* (Lepidoptera: Pyralidae) in Kenya. *Bull. Entomol. Res.* 89: 185-191.

SMITH, J.W. JR, WIEDENMANN, R.N. & OVERHOLT, W.A. 1993. Parasites of Lepidopteran Stemborers of Tropical Gramineous Plants. Nairobi: ICIPE Science Press 89 pp.

VAN DEN BERG, J. & DRINKWATER, T.W. 2000. Pink stemborer. *Plant Protection series* no. 20. ARC Grain Crops Research Institute, Private Bag X1251, Potchefstroom, 2520, South Africa.

VAN HAMBURG, H. 1979. The grain-sorghum stalk-borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae): seasonal changes in adult populations in grain sorghum in the Transvaal. *J. Entomol. Soc. sth. Afr.* 42: 1-9.

VAN HAMBURG, H. 1987. A biological control approach to pest management on grain crops with special reference to the control of stalkborers. *Tech. Commun., Dep. Agric. Water Supply, Rep. S. Afr.* 212: 52-55.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1985. Geographical variation in the seasonal moth flight activity of the maize stalkborer, *Busseola fusca* (Fuller), in South Africa. *S. Afr. J. Plant Soil* 2: 123-126.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1987. Ecology of the maize stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *Bull. Entomol. Res.* 77: 255-269.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1988. Response of maize to levels and times of infestation by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *J. Entomol. Soc. sth. Afr.* 51: 283-291.

WALE, M. 1999. Population dynamics of the stemborers *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller) and *Sesamia calamistis* (Hampson) attacking sorghum in central Ethiopia. *Insect Sci. Appl.* 19: 149-156.

WIEDENMANN, R.N. & SMITH, J.W. 1993. Functional response of the parasite *Cotesia flavipes* (Hymenoptera: Braconidae) at low densities of the host *Diatraea saccharalis* (Lepidoptera: Pyralidae). *Environ. Entomol.* 22: 848-858.

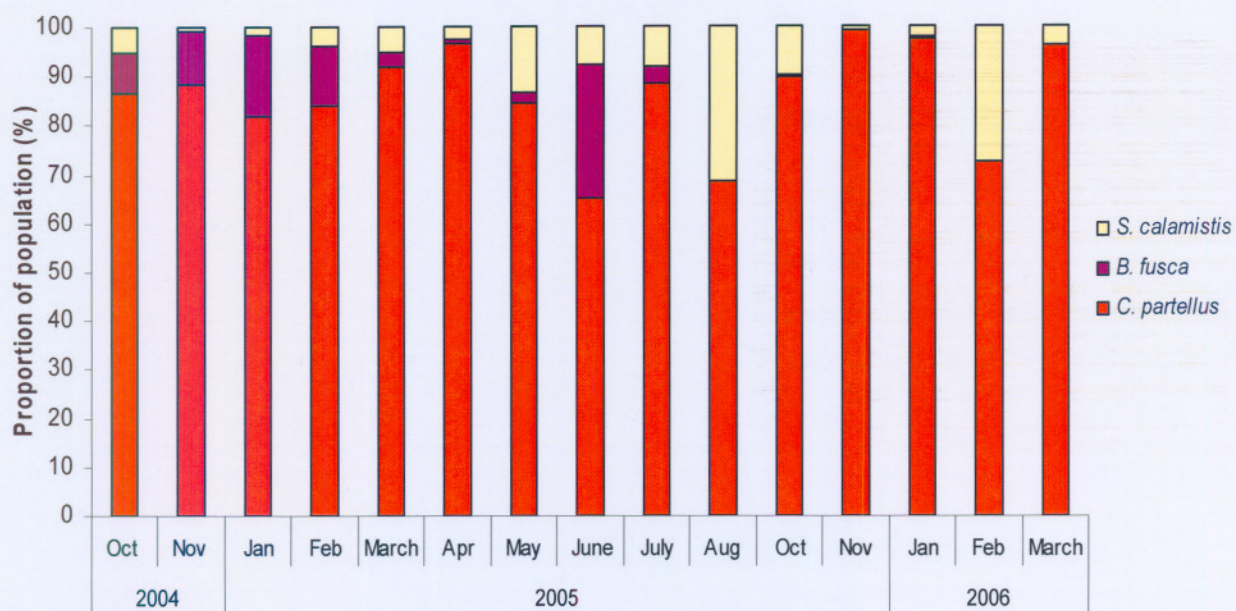


Figure 3.1: Population distribution of *Chilo partellus*, *Busseola fusca* and *Sesamia calamistis* larvae in maize plants at Tshiombo between October 2004 and March 2006.

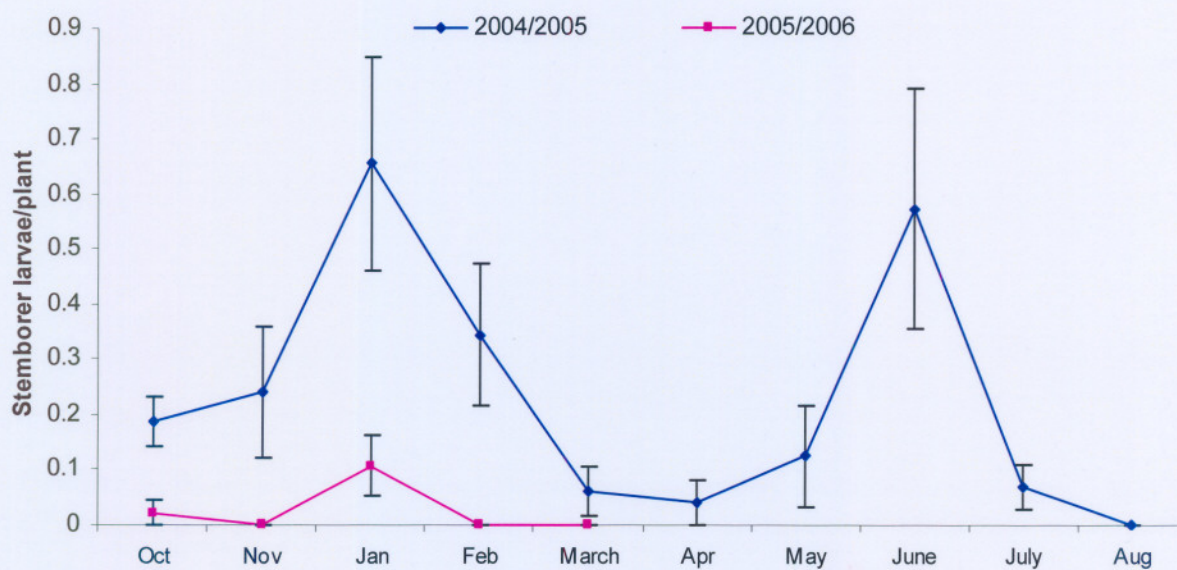


Figure 3.2: Mean number of *Busseola fusca* larvae per plant on maize fields during the pre-flowering period at Tshiombo between October 2004 and March 2006. Bars represent standard errors (SE).

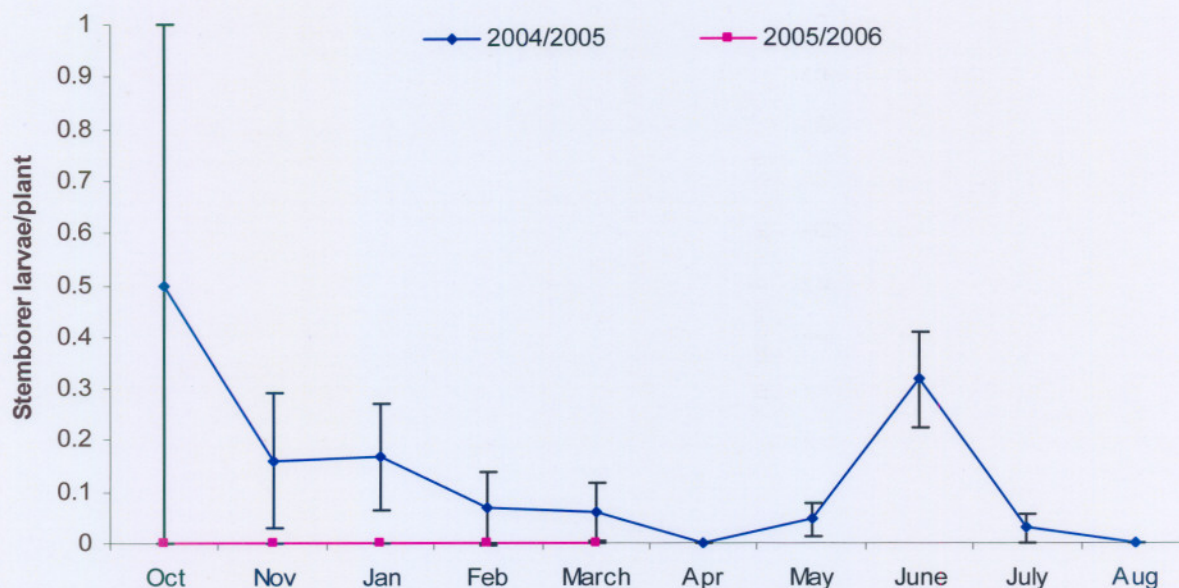


Figure 3.3: Mean number of *Busseola fusca* larvae per plant on maize fields during the post-flowering period between October 2004 and March 2006. Bars represent standard errors (SE).

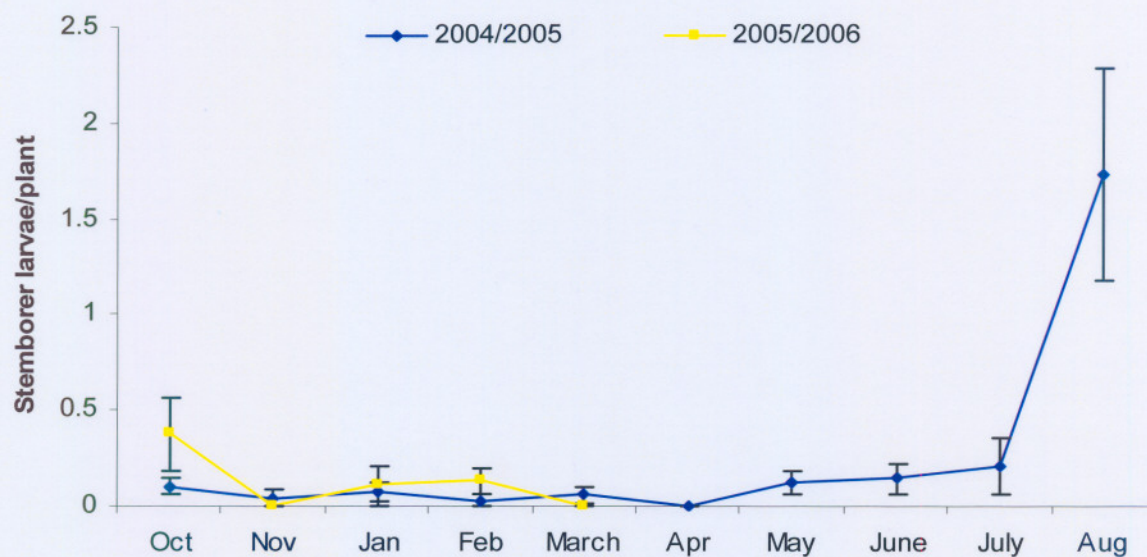


Figure 3.4: Mean number of *Sesamia calamistis* larvae per plant on maize fields during the pre-flowering period between October 2004 and March 2006. Bars represent standard errors (SE).

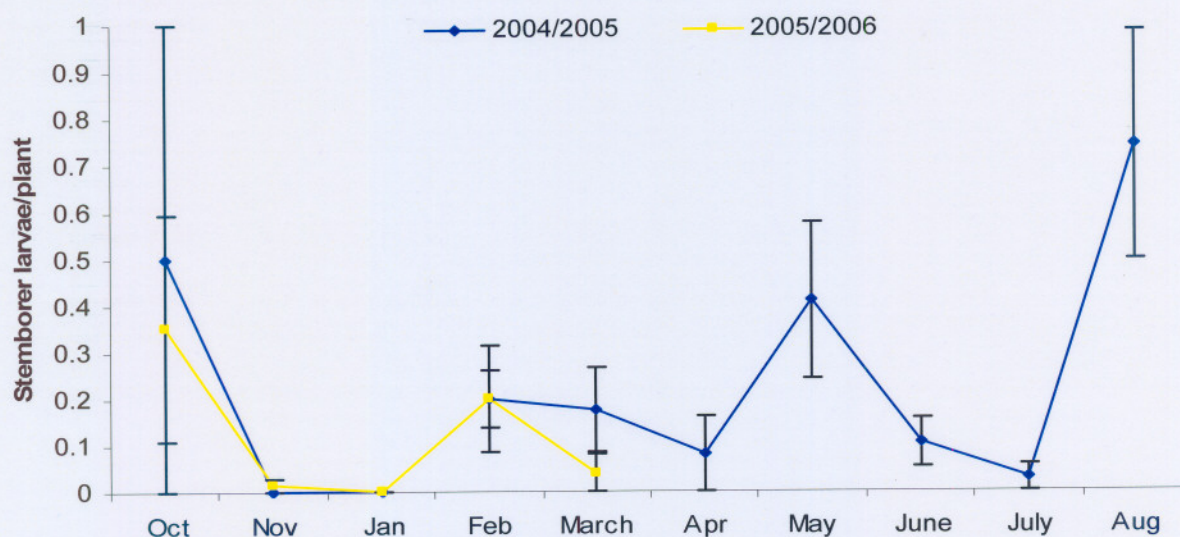


Figure 3.5: Mean number of *Sesamia calamistis* larvae per plant on maize fields during the post-flowering period between October 2004 and March 2006. Bars represent standard errors (SE).

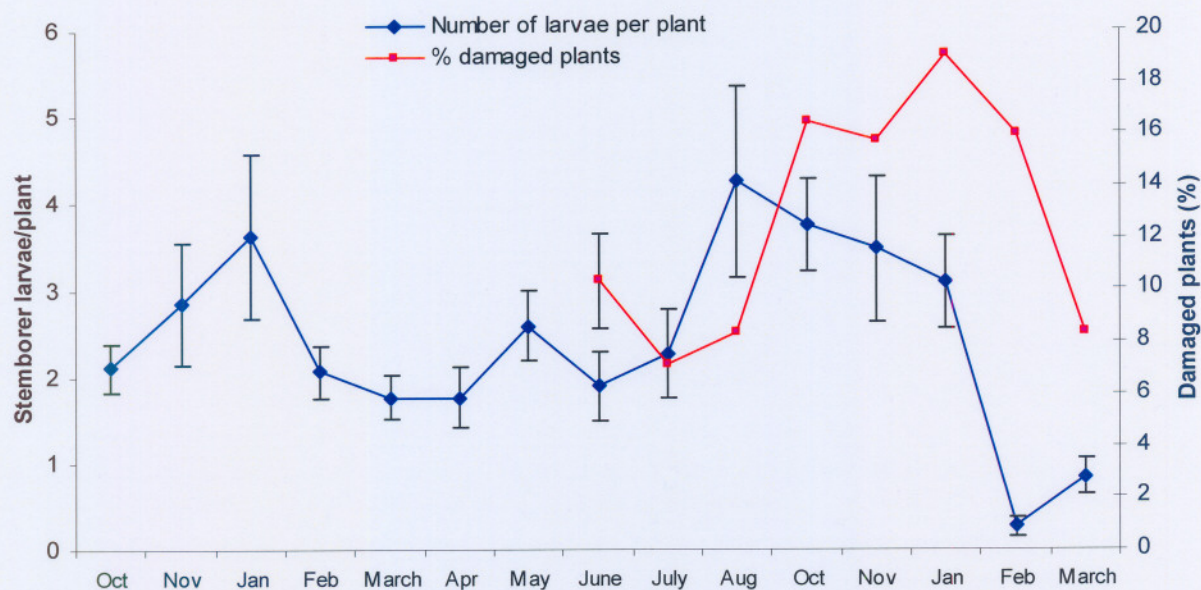


Figure 3.6: Mean number of *Chilo partellus* larvae per plant and incidence of stemborer damaged plants on maize fields during the pre-flowering period between October 2004 and March 2006. Bars represent standard errors (SE).

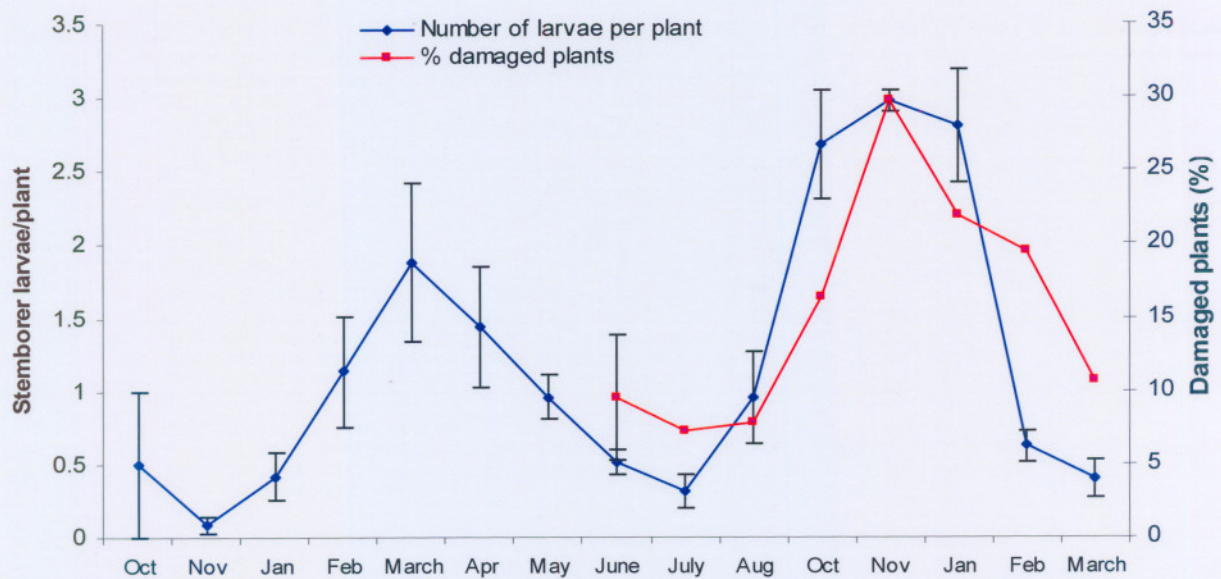


Figure 3.7: Mean number of *Chilo partellus* larvae per plant and incidence of stemborer damaged plants on maize fields during the post-flowering period between October 2004 and March 2006.

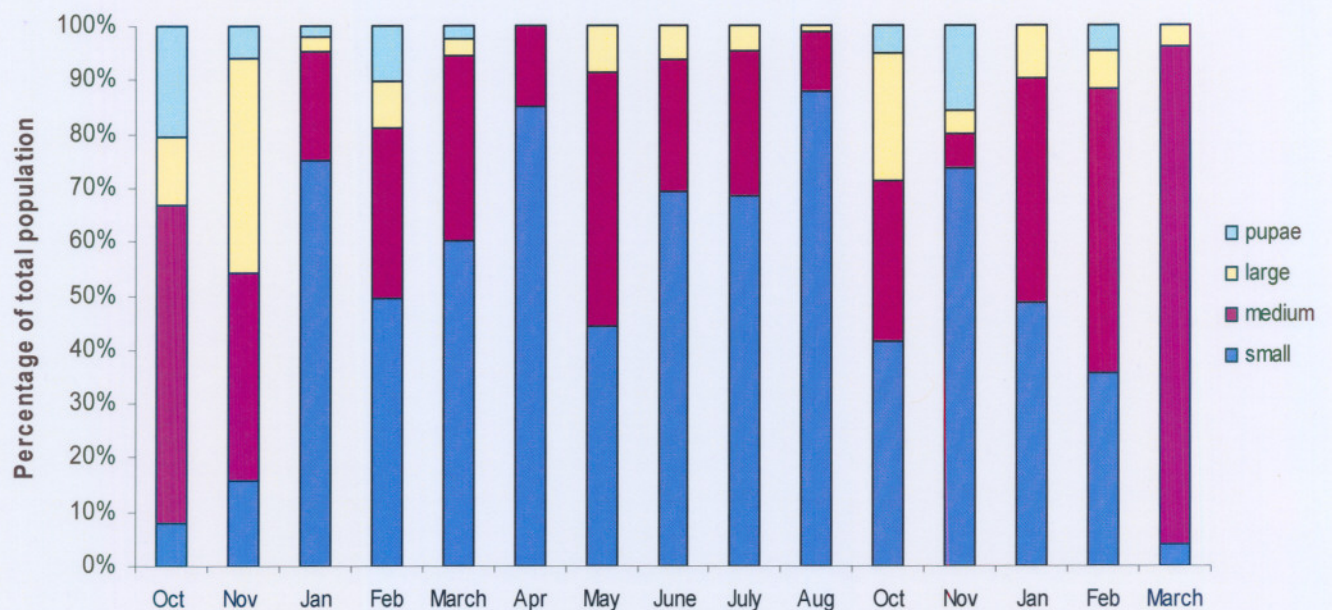


Figure 3.8: The percentage size distribution of *Chilo partellus* from October 2004 to March 2006 at the Tshiombo irrigation scheme.

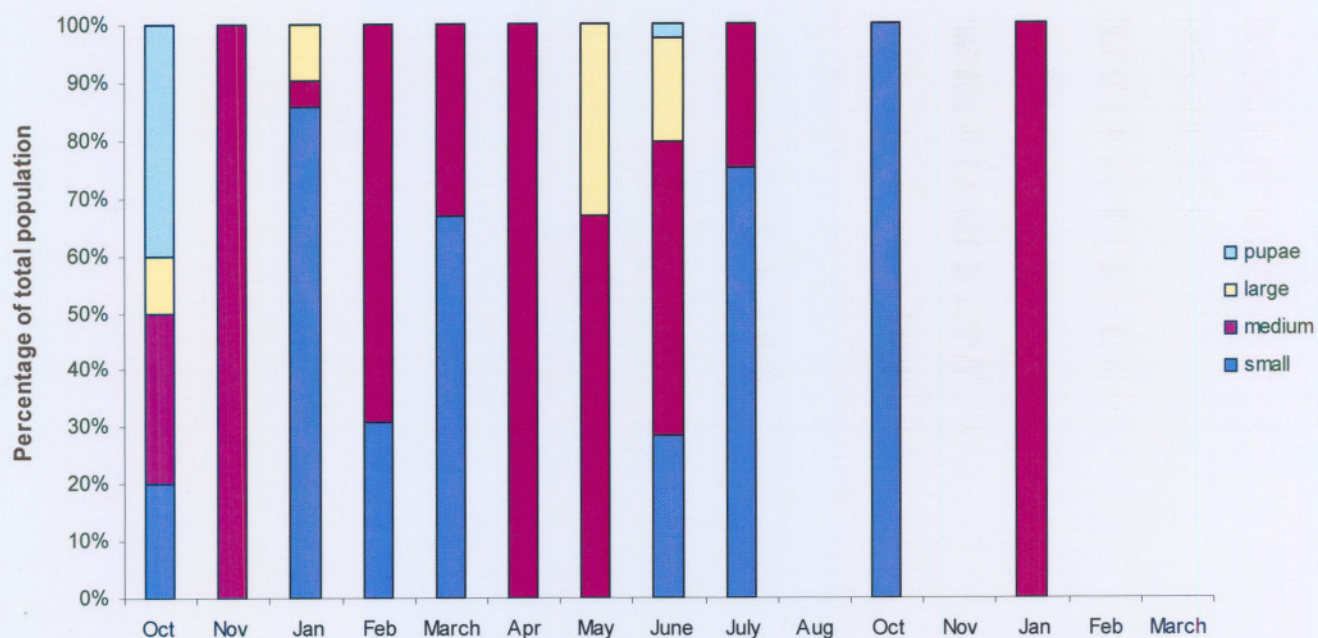


Figure 3.9: The percentage size distribution of *Busseola fusca* from October 2004 to March 2006 at the Tshiombo irrigation scheme.

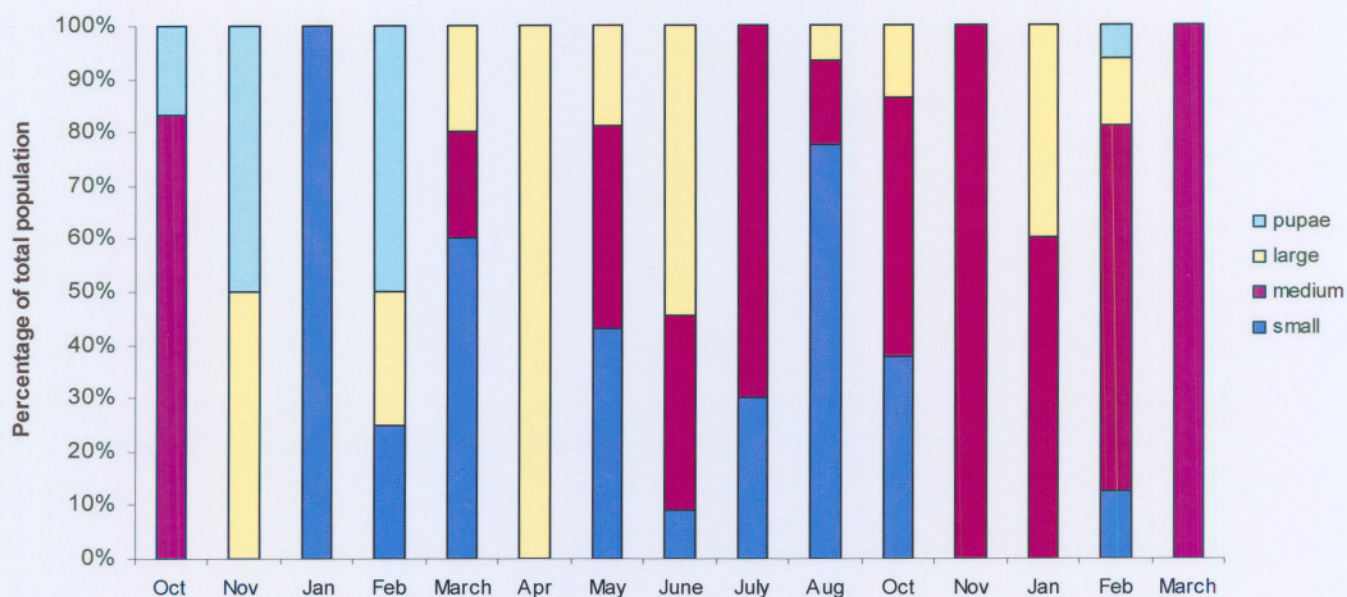


Figure 3.10: The percentage size distribution of *Sesamia calamistis* from October 2004 to March 2006 at the Tshiombo irrigation scheme.

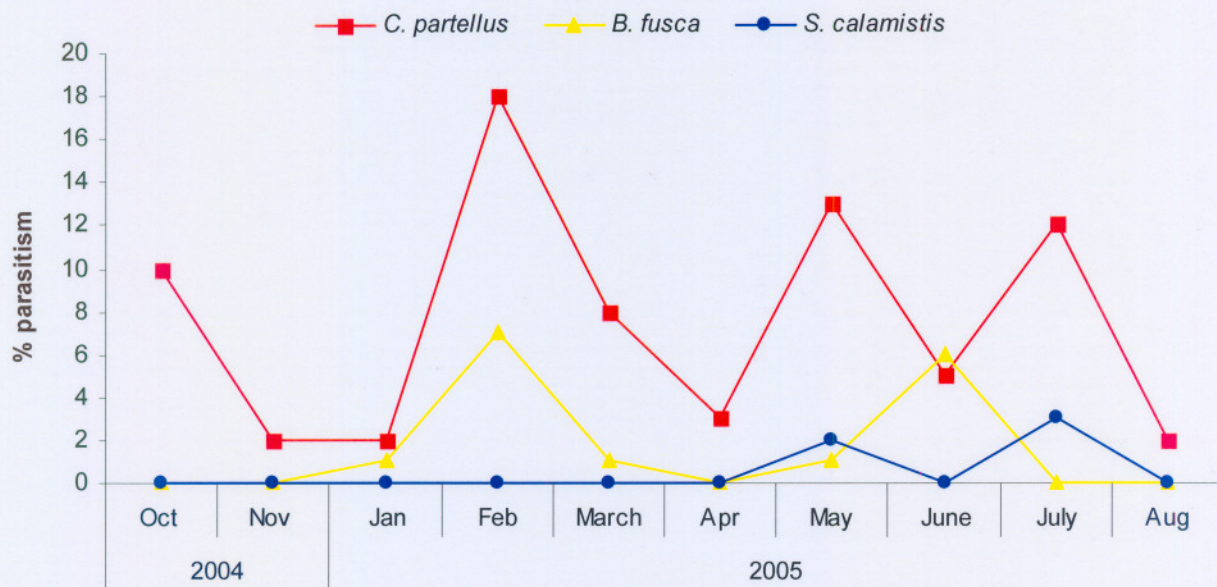


Figure 3.11: The percentage parasitism by the larval parasitoid *Cotesia sesamiae* on three stemborer species from October 2004 to August 2005 at the Tshiombo irrigation scheme.

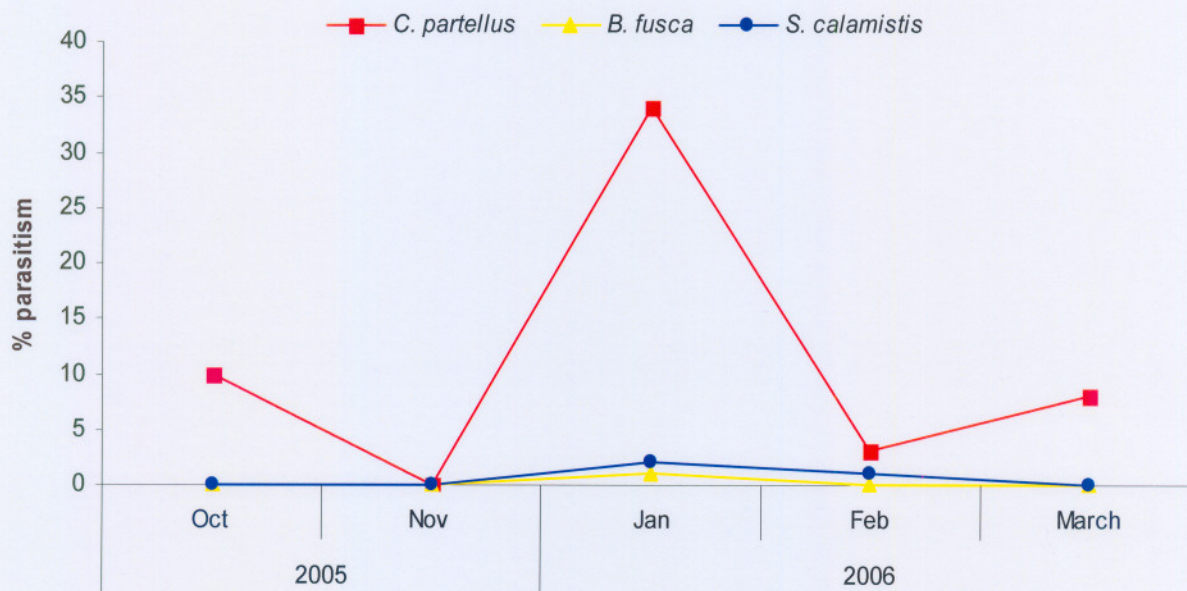


Figure 3.12: The percentage parasitism by the larval parasitoid *Cotesia sesamiae* on three stemborer species from October 2005 to March 2006 at the Tshiombo irrigation scheme.



Figure 3.13: Labelling field collected samples at Tshiombo.



Figure 3.14: *Busseola fusca* larva feeding on ear of a maize plant.



Figure 3.15: *Chilo partellus* larvae feeding on maize leaf.

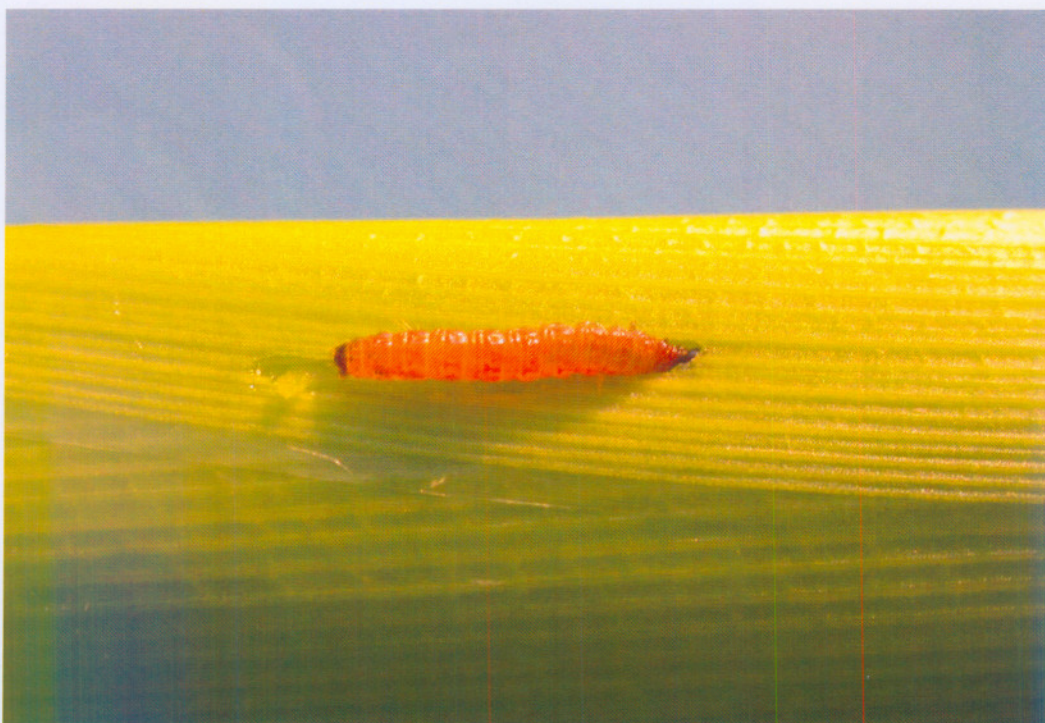


Figure 3.16: *Sesamia calamistis* larva feeding in a maize plant.



Figure 3.17: *Cotesia sesamiae*, cocoons and adults that emerged from a *Chilo partellus* larva.



Figure 3.18: *Dentichasmias busseolae* (right) emerged from a *Chilo partellus* pupa.

CHAPTER 4: The effect of *Pennisetum purpureum* (Schumacher) as trap crop on the incidence of damaged plants and numbers of Lepidopterous stemborers in maize

4.1 Introduction

Maize (*Zea mays*) is the most important crop produced by resource-poor farmers in South Africa. The stemborers *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) and *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) are important pests of maize in the Limpopo Province of South Africa (Van den Berg, Rebe, Du Bruyn & Van Hamburg, 2001). *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) is also economically important in South Africa (Van den Berg & Van Wyk, 2006). These lepidopteran larvae attack maize from the seedling to post-flowering stages and cause damage that results in yield losses of between 20 – 80 % (Khan *et al.*, 1997a).

The suitability of a given crop as host plant is a combination of its attractiveness to moths and its ability to support larval development (Van Rensburg, Walters & Giliomee, 1989). Ingram (1958) found that Napier grass (*Pennisetum purpureum*) (Schumacher) (Fig. 4.9) was more readily attacked by stemborers than maize. Similarly, Khan, Midega, Hutter, Wilkins & Wadhams (2006) found that *C. partellus* preferentially chose Napier grass varieties for oviposition over maize in a two-choice test. Subsequent larval survival was significantly lower on the majority of Napier grass varieties (10 %) than on maize (60 %). Preference of *B. fusca* and *C. partellus* moths for oviposition on certain Napier grass varieties was shown by Van den Berg, De Bruyn & Van Hamburg (2006) and Van den Berg (2006), respectively. Observations made in Kenya in maize plots with a border of Napier grass, showed that there was considerably more oviposition and early larval development on the trap crop compared with maize. However, only 20 % of the larvae survived on the Napier grass, whereas 80 % survived through to adults on the maize (Khan *et al.*, 2000). The preference of stemborer moths for certain host plants and subsequent poor larval survival has been exploited to develop a habitat management system for stemborers. In this system wild grasses are used as trap crops for stemborers in a 'push-pull' or stimulo-deterrent diversionary strategy where Napier grass is used to concentrate oviposition away from maize

crops and to reduce subsequent population development (Khan, Pickett, Van den Berg, Wadhams & Woodcock, 2000; Van den Berg *et al.*, 2001).

Although pesticides can be used to alleviate problems, they are too expensive for general use in small-farming circumstances, which often involve small family farms of less than one hectare (Khan *et al.*, 2000). Alternative treatments include the use of fire ash against stemborers, but the favoured approach is to use intercropping systems. The mechanisms of these systems have generally been poorly researched, so that even when there is relief of pest problems, maximisation of the effects has not been possible (Khan *et al.*, 2000).

Whereas the Napier grass habitat management system in east Africa uses grass barriers on all sides of the field, adaptations have been made in South Africa. Local farming systems and the common use of tractors necessitate the planting of Napier grass only on contours. The grass is therefore not planted as a barrier around maize fields but only as long contour strips along two sides of fields (Fig. 4.10). Since this adapted system does not include all the components of the push-pull system, the Napier grass only functions as a trap crop.

The objective of this study was to determine if this adapted habitat management system with Napier grass as trap crop on contours would be effective in reducing stemborer infestation levels in maize and if it would also affect the stemborer species composition inside fields surrounded by the trap crop.

4.2 Materials and Methods

The study was conducted at the Tshiombo irrigation scheme (S22°47.863", E030° 27.194", 635 m a.s.l.), north-east of Thohoyandou in the Limpopo Province. Approximately 930 plots each 1.2 ha in size, make up the irrigation scheme at Tshiombo (Lahiff, 1997). Planting of maize is continuous and fields at different growth stages interspaced with large natural areas or other crops such as sweet potatoes, groundnut and cabbage are characteristic of the small-farming system at this irrigation scheme.

For this field experiment, which was conducted between May and November 2005, use was made of the well established 2-contour Napier grass system that is currently used by many farmers at the irrigation scheme. These contours were established during the past three years and there were therefore well established rows of Napier grass that were between 1 – 1.5 m wide. During the experiment the Napier grass was always taller than maize and reached a height of between 2 – 3 m at the time that maize plants flowered. At seedling emergence the Napier grass on contours was already 1.0 m high. Maize fields differed in size and were approximately 60 – 80 m in length and between 12 – 16 m wide.

The incidence of stemborer infested plants was determined on 16 fields with Napier grass on the contours (trap crop fields) and compared to fields in close proximity without Napier grass on contours (control fields). Twelve of these fields were sampled during the mid-whorl stage and four fields during the flowering to soft dough stage of crop development.

Inside each field the incidence of plants exhibiting whorl damage symptoms was determined on 16 randomly selected plots (pseudo replicates). Plants that were in the post-flowering stage were examined for stemborer damage to the upper most leaves as well as maize ears. Each replicate consisted of a row of between 16 – 20 plants. Maize is planted in short rows on ridges at this irrigation scheme to facilitate the flood irrigation system that is still managed by hand. Plant stand and the number of plants exhibiting stemborer damage symptoms were determined in each plot. The incidence of infested plants was expressed as a percentage of the plant stand per plot and the mean calculated for each field. To determine stemborer species composition and larval infestation levels between 2 and 13 randomly selected plants exhibiting stemborer damage symptoms were removed from each field and dissected.

Two-way factorial analyses of variance (ANOVA) using the statistical package STATISTICA (StatSoft Inc., 2005) were done on the incidence of stemborer infested plants to determine if there were interactions between treatments (trap and control). The data were transformed using a log (x+1) transformation. One-way ANOVAs were done to compare infestation levels of trap and control fields, while T-tests were performed to determine if there were significant differences in infestation levels between treatments for each pair of fields. T-tests were also done to determine

if there were significant differences in mean number of *C. partellus*, *B. fusca* and *S. calamistis* larvae between each treatment pair. Fisher exact tests (using the SAS System, SAS Institute Inc., 2002-2003) were done to show relationships (if any) between treatments (trap and control) and the three stemborer species. Significance was set at $P < 0.05$ for all analyses.

4.3 Results and discussion

4.3.1 Incidence of damage on plants in the mid-whorl stage

The incidence of damaged plants throughout the experiment was generally low and ranged between 3.8 – 24.5 % in control fields and between 0.4 – 8.0 % in fields with the trap crop (Table 4.1, Fig. 4.1, 4.2). For the purpose of this study control fields which showed less than 10 % damaged plants were considered as having a low infestation level. The interactions between trap and control fields were highly significant ($F_{(11, 360)} = 3.86$, $P = 0.00003$) (Fig. 4.2). It was therefore decided to analyse the pairs of trap and control fields separately by means of one-way ANOVAs followed by a Tukey post hoc test to compare the means of the fields in a pairwise manner. The highest mean percentage damage of all fields was 24 % (control field 12), which differed significantly from all other control fields (Table 4.1, Fig. 4.1, 4.2).

Results of the t-tests done to determine if differences existed between the mean percentage, damaged plants in the trap and control treatments are provided in Table 4.1. Ten of the 12 fields had lower incidences of damaged plants in trap crop fields than the control fields, but only six of these were significantly lower ($P < 0.05$) (Table 4.1, Fig. 4.1, 4.2). Field 6, which had 9.7 % infested plants, was rounded off to 10 % and was therefore included in the discussion in the group of fields with infestation levels $\geq 10\%$. Of the seven control fields which had a low percentage damage ($< 10\%$), five showed no significant differences between the trap and control fields (Table 4.1, Fig. 4.1, 4.2). Four of the five fields which had a mean percentage damage of 10 % or higher showed significant differences ($P < 0.05$) between trap and control fields (Table 4.1). In contrast, most of the fields with low damage incidence showed little significant effect ($P > 0.05$) except for field 5 ($P = 0.0003$; $t = -4.10$) and field 8 ($P = 0.04$; $t = -2.17$) (Table 4.1). The

tendency seems to indicate that the trap crop showed promise to reduce the incidence of stemborer damaged plants at higher stemborer population pressure.

The species composition expressed as a percentage of the total stemborer population at each sampling date is provided in Figure 4.3. *Chilo partellus* was the dominant species with proportions of between 67 – 100 % of the population in the trap crop fields and 88 – 100 % in the control fields (Fig. 4.3). Fisher exact tests were done to show relationships (if any) between treatments (trap and control) and stemborer species (data not shown). Field 1, 3, 6, 8 and field 9 showed no significant differences between species composition between the trap and control treatments (Fig. 4.3). Fischer exact tests were not applicable to other pairs of fields because only *C. partellus* was recorded. The results on possible stemborer species differences between trap and control fields are therefore inconclusive.

A large variation in larval numbers / plant was observed and numbers ranged between 1 – 4.5 / plant in control fields and 0.5 – 1.7 / plant in trap crop fields (Fig. 4.4). T-tests were done to determine if there were differences between the mean number of *C. partellus*, *S. calamistis* and *B. fusca* larvae / plant between trap and control fields (data not shown). No significant differences were observed between numbers of different species / plant between trap and control fields.

4.3.2 Incidence of damage on plants during the post-flowering period

During the post-flowering stage the incidence of damage was between 15.5 – 35.6 % on control fields and 7.0 – 16.8 % on trap crop fields (Table 4.1, Fig. 4.5, 4.6). Factorial analysis (ANOVA) indicated a highly significant interaction between the trap and control treatments ($F_{(3; 120)} = 8.02$, $P = 0.00006$). It was therefore decided to analyse data of each pair of fields separately by means of one-way ANOVAs followed by a Tukey post hoc test to compare the means of the fields in a pair wise manner.

T-tests were done to determine differences in the mean percentage damaged plants on trap and control fields (Table 4.1, Fig. 4.5, 4.6). There were significant differences in infestation levels of different fields over time ($P < 0.05$) (Table 4.1, Fig. 4.5, 4.6). Three of the four fields with the

Napier grass trap crop had significantly fewer ($P < 0.05$) stemborer damaged plants (Table 4.1, Fig. 4.5, 4.6).

During the post-flowering period, *C. partellus* proportions ranged between 66 – 100 % in the trap crop fields and 29 – 100 % in the control fields (Fig. 4.7). In May (field 2) (Figure 4.7) *S. calamistis* made up 63 % of the population in the control field compared to the 29 % of *C. partellus* and 8.3 % for *B. fusca* (Fig. 4.7). In cases where significant differences were observed between the incidences of damaged plants in trap and control fields (Fig. 4.7) *C. partellus* was always present in high proportions (> 95 %) and *S. calamistis* was always absent. Fisher exact tests were done to determine if relationships existed between treatments (trap and control) and species (data not shown). Only in field 2 a significant difference ($P = 0.04$) was observed between treatment and species. This was the only field in which *S. calamistis* dominated (63 %). *Chilo partellus* made up 29 % and *B. fusca* 8.3 % of the population.

Larval numbers ranged between 0.2 – 2.2 / plant on control fields and 0.2 – 1.8 / plant in trap crop blocks (Fig. 4.8) during the post-flowering period. T-tests showed significant differences between mean number of *S. calamistis* and *B. fusca* / plant. *Sesamia calamistis* had a maximum of 1.36 larvae / plant (63 % of the total species composition) and *C. partellus* only 0.63 larvae / plant (29 %) of species. Results show a tendency that the trap crop may not be effective on plants after flowering if *S. calamistis* forms a significant proportion of the stemborer population.

Although only two borders of Napier were planted on contours adjacent to maize plots Khan, Chiliswa, Ampong-Nyarko, Smart, Polaszek *et al.* (1997b) showed that planting forage grasses such as Napier as borders significantly reduced attacks by *C. partellus* and *B. fusca* and thereby increased maize yields. Similarly according to Ndemah, Gounou & Schulthess (2002) *S. calamistis* densities tended to be lower in maize surrounded by Napier grass. However, these differences were only observed in certain growing seasons.

The lower incidence of infestation in several blocks with Napier grass as trap crop showed that this method of pest control could be effective under certain conditions. Although eggs were not sampled the reduced incidence of damage could possibly be ascribed to moths laying eggs on trap

plants and a subsequently reduced egg load of moths that do infest the maize crop after encountering the trap crop. In both the humid forest and the derived savanna of western Africa, grasses grown as border rows around maize plots lead to reduced pest densities in maize caused by an increase in plant-induced mortality occurring on grasses or an increase in parasitism (Ndemah, Gounou & Schultess, 2002). Because of its non-determinant growth pattern and, thereby, continuous availability of plant parts suitable for oviposition and growth and development of immatures, *P. purpureum* forms a much more stable habitat for both pests and natural enemies than maize (Ndemah, Schulthess, Poehling, Borgemeister & Goergen, 2001).

Future research should be aimed at clarifying the differential levels of success of Napier grass as trap crop under different levels of pest pressure and/or environmental conditions. This pest management technique together with the mass-release of a natural enemy like *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) against the dominant *C. partellus* could suppress stemborer numbers to limit damage to maize plants.

4.4 References

- INGRAM, W.R.** 1958. The Lepidopterous stalk borers associated with Gramineae in Uganda. *Bull. Entomol. Res.* 49: 367-383.
- KHAN, Z.R., AMPONG-NYARKO, K., CHILISWA, P., HASSANALI, A., KIMANI, S., LWANDE, W., OVERHOLT, W.A., PICKETT, J.A., SMART, L.E., WADHAMS, L.J. & WOODCOCK, M.**, 1997a. Intercropping increases parasitism of pests. *Nature* 388: 631-632.
- KHAN, Z.R., MIDEGA, C.A.O., HUTTER, N.J., WILKINS, R.M. & WADHAMS, L.J.** 2006. Assessment of the potential of Napier grass (*Pennisetum purpureum*) varieties as trap plants for management of *Chilo partellus*. *Entomol. Exp. Appl.* 119: 15-22.
- KHAN, Z.R., PICKETT, J.A., VAN DEN BERG, J., WADHAMS, L.J. & WOODCOCK, C.M.** 2000. Exploiting chemical ecology and species diversity: stemborer and *Striga* control for maize and sorghum in Africa. *Pest Manag. Sci.* 56: 957-962.
- LAHIFF, E.** 1997. Rural resources rural livelihoods working paper series: Land, water and local governance in South Africa: A case study of the Mutale River Valley. *Paper no. 7*. The economic and Social Research Council. Global environmental Change Programme Phase 3 project: *Dryland*.
- MOHAMED, H.M., KHAN, Z.R., OVERHOLT, W.A. & ELIZABETH, D.K.** 2004. Behaviour and biology of *Chilo partellus* (Lepidoptera: Pyralidae) on maize and wild gramineous plants. *Int. J. Trop. Insect Sci.* 24: 287-297.
- NDEMAH, R., GOUNOU, S. & SCHULTHESS, F.** 2002. The role of wild grasses in the management of lepidopterous stemborers on maize in the humid tropics of western Africa. *Bull. Entomol. Res.* 92: 507-519.

NDEMAH, R., SCHULTHESS, F., POEHLING, M., BORGEMEISTER, C. & GOERGEN, G. 2001. Natural enemies of Lepidopterous borers on maize and elephant grass in the forest zone of Cameroon. *Bull. Entomol. Res.* 91: 205-212.

SAS INSTITUTE, INC. 2002 – 2003. The SAS system for Windows Release 9.1 TS Level IMO Copyright © by SAS Institute Inc., Cary, NC, USA.

STATSOFT, INC. 2005. Statistica (data analysis software system), version 7.1. www.statsoft.com.

VAN DEN BERG, J. 2006. Oviposition preference and larval survival of *Chilo partellus* (Lepidoptera: Pyralidae) on Napier grass (*Pennisetum purpureum*) trap crops. *Int. J. Pest Manag.* 52: 39–44.

VAN DEN BERG J., DE BRUYN, A.J.M. & VAN HAMBURG, H. 2006. Oviposition preference and survival of the maize stem borer, *Busseola fusca* (Lepidoptera: Noctuidae) on Napier grasses (*Pennisetum* spp.) and maize. *Afr. Entomol.* 14: 211-218.

VAN DEN BERG, J., REBE, M., DE BRUYN, A.J.M. & VAN HAMBURG, H. 2001. Developing habitat management systems for graminaceous stemborers in South Africa. *Insect Sci. Appl.* 21: 381-388.

VAN DEN BERG, J. & VAN WYK, A. 2006. The effect of Bt maize on *Sesamia calamistis* (Lepidoptera: Noctuidae) in South Africa. *Entomol. Exp. Appl.* In press.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOME, J.H. 1989. Selective oviposition by the maize stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *J. Entomol. Soc. sth. Afr.* 52: 105-108.

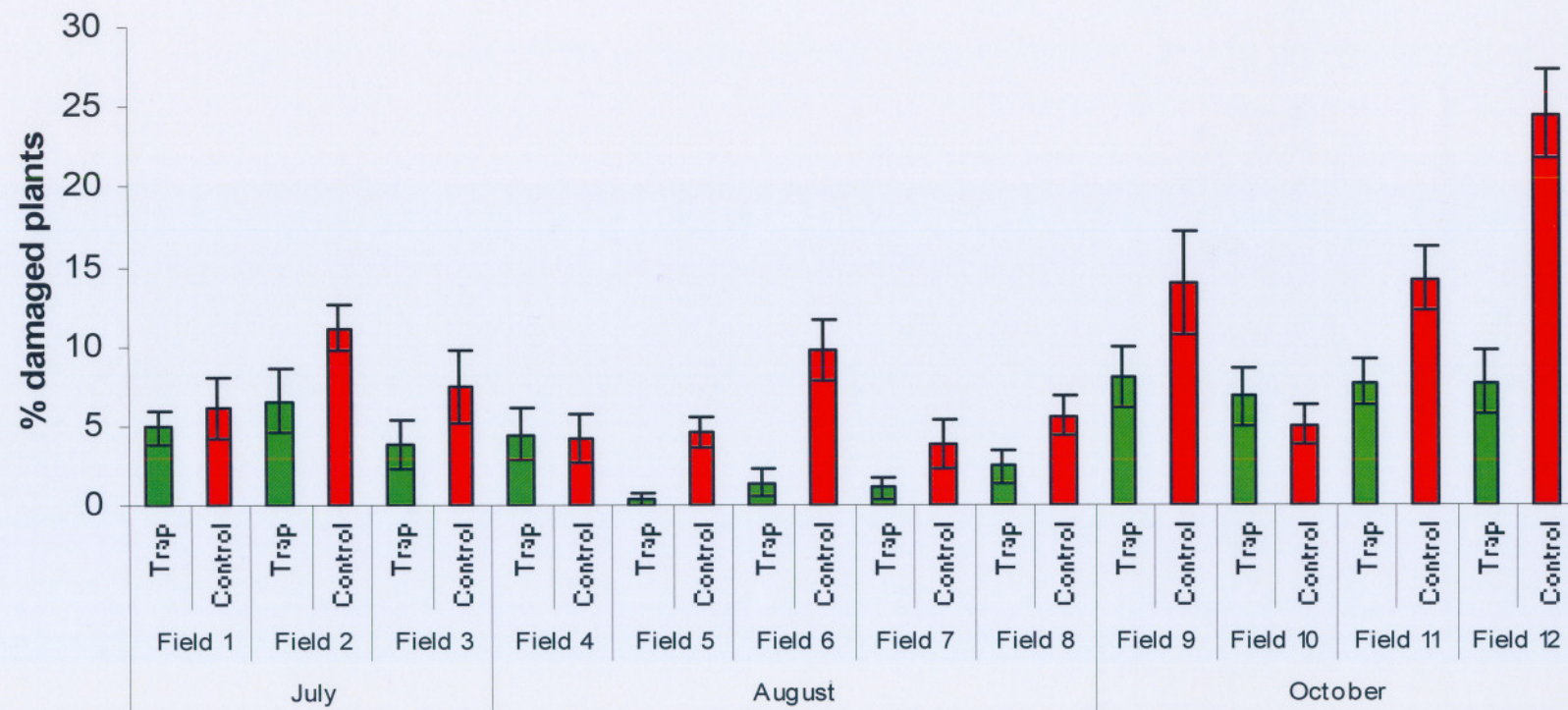


Figure 4.1: The mean percentage stemborer damaged plants on maize fields with and without Napier grass on contours during the pre-flowering period. Bars represent standard errors (SE).

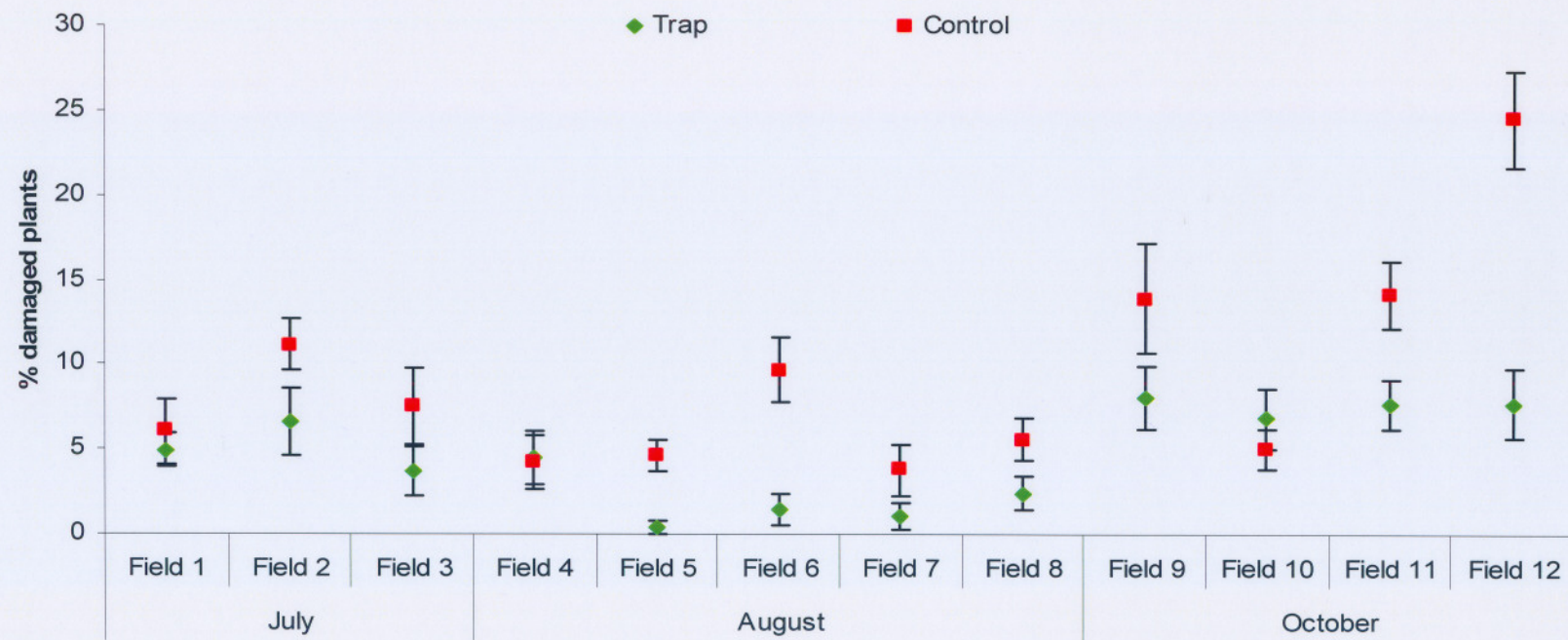


Figure 4.2: Infestation levels on twelve pairs of fields (F1 - 12) (trap and control fields) during the pre-flowering period (July, August and October 2005). Bars represent standard errors (SE).

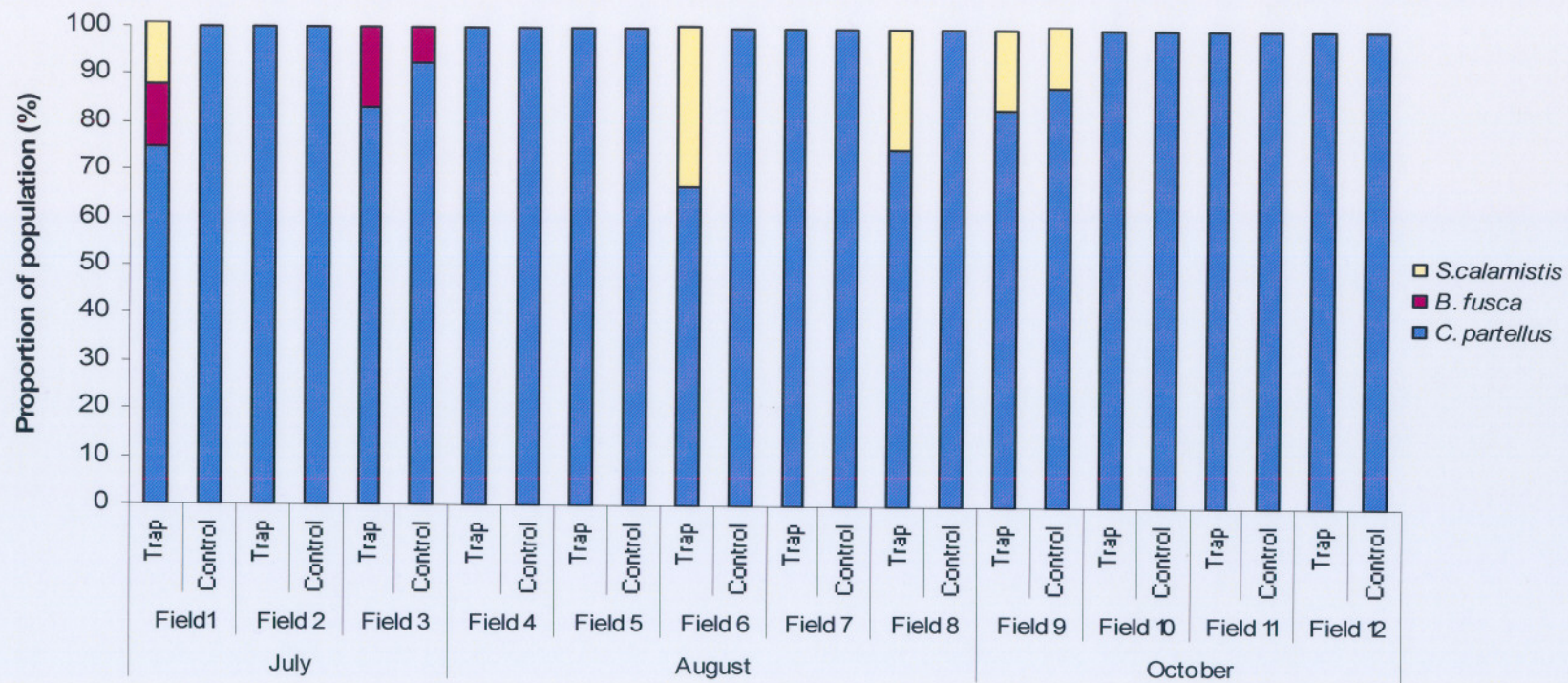


Figure 4.3: Species composition (%) of the total number of stemborer larvae collected from plants during the pre- flowering period on fields with and without Napier grass as trap crop.

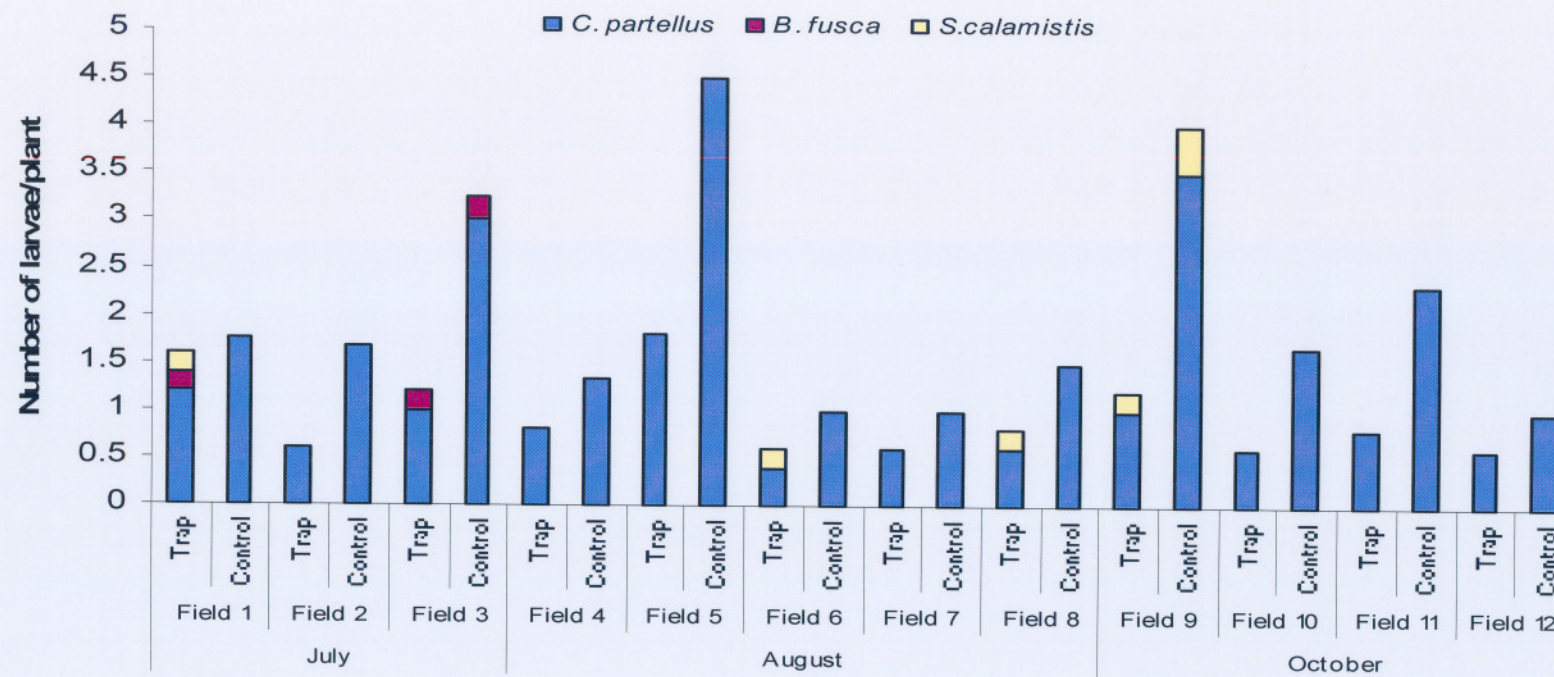


Figure 4.4: The number of stemborer larvae per plant on maize fields with and without Napier grass on contours (during the pre-flowering period).

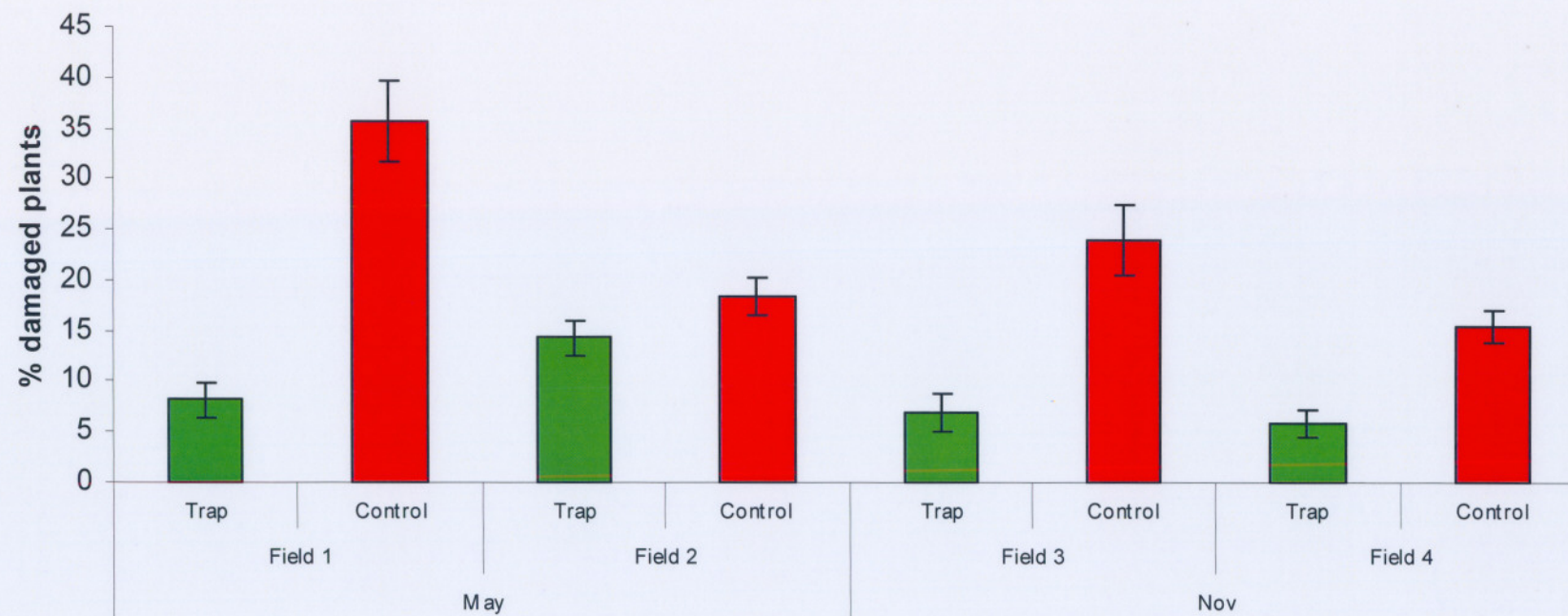


Figure 4.5: The mean incidence (%) of stemborer damaged plants on maize fields during the post-flowering stage with and without Napier grass on contours. Bars represent standard errors (SE).

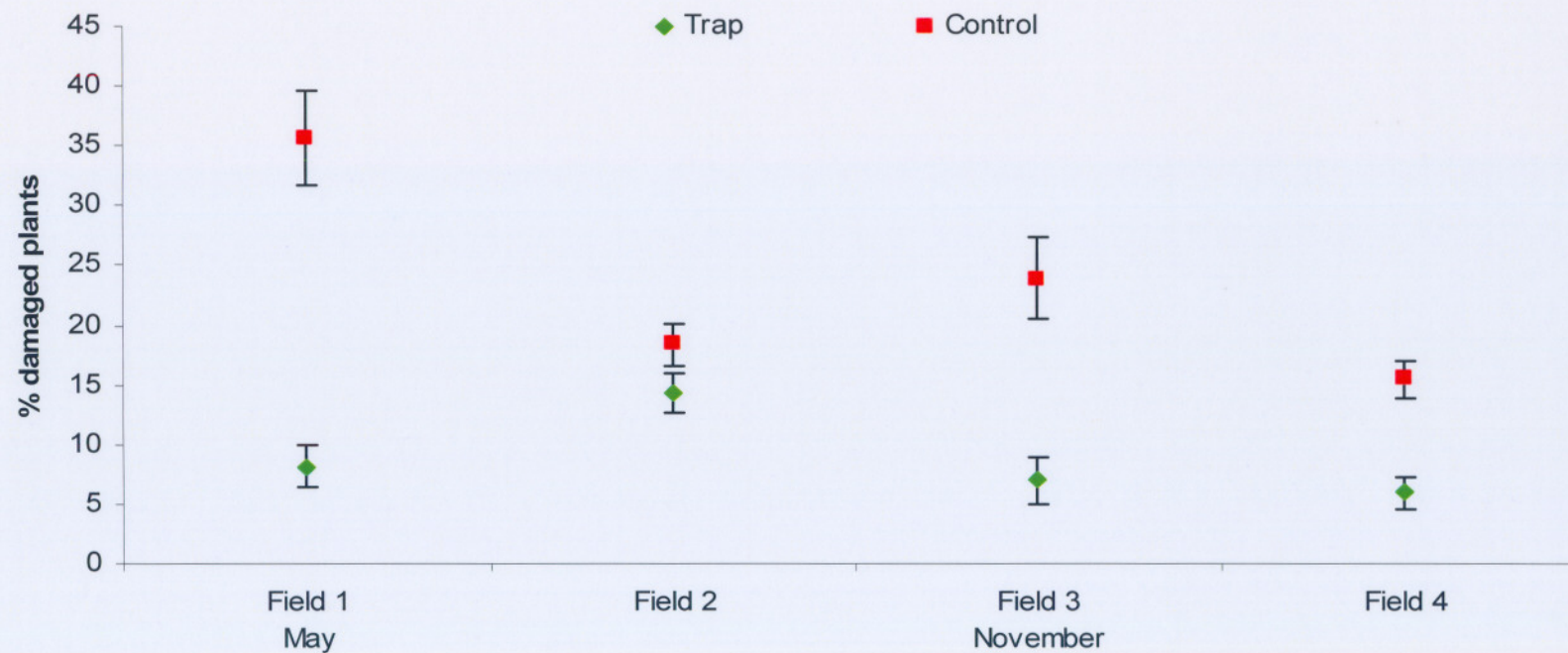


Figure 4.6: Infestation levels in four different fields (F1- 4) showing interactions between treatments (trap and control fields) during the post-flowering period (May and November 2005). Bars represent standard errors (SE).

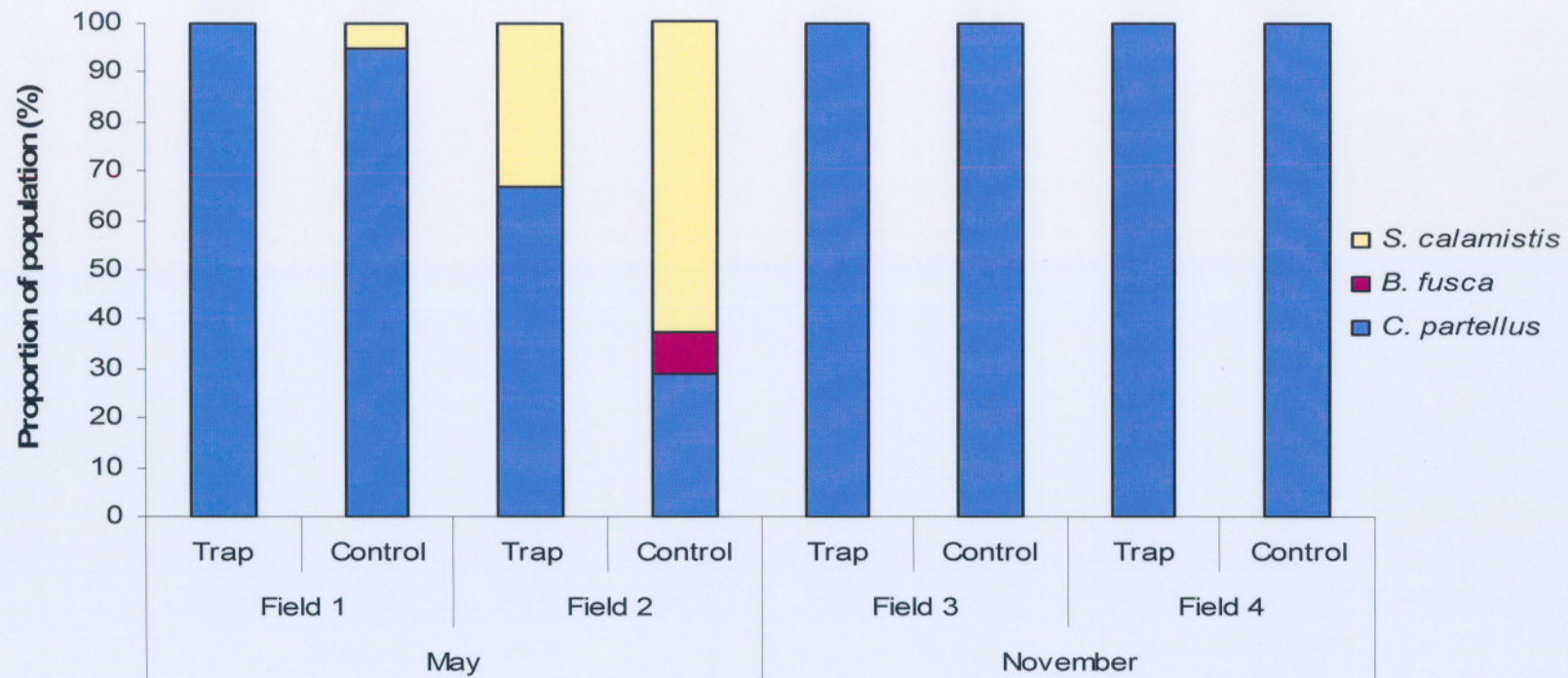


Figure 4.7: Species composition (%) of the total number of stemborer larvae collected from plants during the post- flowering period on fields with and without Napier grass as trap crop.

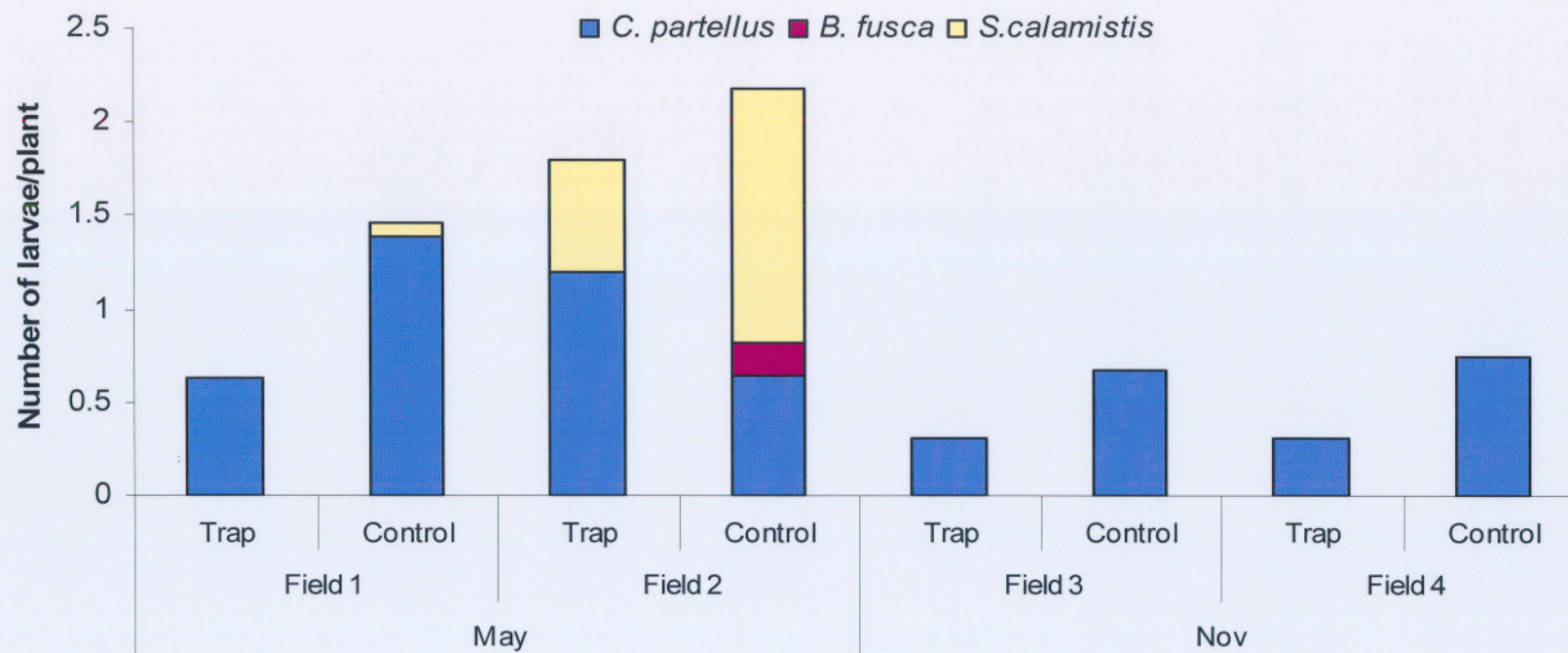


Figure 4.8: The mean number of stemborer larvae / plant on maize fields during the mid-whorl stage on fields with and without Napier grass on contours.

Table 4.1: The mean percentage stemborer damaged plants in trap and control fields during the pre- and post-flowering stages.

Pre-flowering period				
Mean % infested plants				
Field	Trap Crop fields	Control fields	t-value	P-value
July				
Field 1	4.9	6.1	0.40	0.69
Field 2	6.6	11.2	2.53	0.02
Field 3	3.8	7.5	1.19	0.24
August				
Field 4	4.5	4.2	0.20	0.85
Field 5	0.4	4.6	4.10	0.0003
Field 6	1.4	9.7	5.19	0.0001
Field 7	1.1	3.8	1.90	0.07
Field 8	2.4	5.6	2.17	0.04
October				
Field 9	8.0	13.9	0.56	0.58
Field 10	6.8	5.0	0.32	0.75
Field 11	7.7	14.2	2.16	0.04
Field 12	7.7	24.5	4.71	0.000020
Post-flowering period				
May				
Field 1	8.2	35.6	5.87	0.0001
Field 2	16.8	21.4	1.38	0.18
November				
Field 3	7.0	23.9	3.80	0.0007
Field 4	5.9	15.5	4.15	0.0003



Figure 4.9: Large Napier grass (*Pennisetum purpureum*) planted as a contour next to a maize field.



Figure 4.10: Napier grass borders on sides of a maize field.

CHAPTER 5: Conclusions

Stemborers are a constraint to maize production throughout sub-Saharan Africa. Extensive research has been done on stemborers in commercial maize production systems in South Africa but not in small-scale farming systems. Hence, no information exists on the ecology of these pests and their natural enemies in maize production systems such as that at the Tshiombo irrigation scheme in Venda. This unique irrigation scheme makes it a challenge to manage stemborer pest populations as water is always available and maize is planted throughout the year. Integrated pest management strategies are needed as pesticides are expensive, time consuming to apply and farmers often do not have the know-how.

To develop an integrated stemborer management strategy, research addressing several objectives was conducted at the Tshiombo irrigation scheme. Research objectives were to:

- determine moth flight patterns of stemborers in order to determine periods of increased moth activity that could be used to predict the timing of pest outbreaks;
- study the relative abundance of stemborers, and their parasitoids to provide information on species distribution and population dynamics as well as which parasitoids occur in this region;
- determine the effect of Napier grass trap crops on stemborer infestation levels.

Three stemborer species occurred at Tshiombo and their relative importance differed in the maize crops at different times of the year. At Tshiombo, fields of different growth stages are interspaced with large natural areas. Maize is planted in short rows on ridges to facilitate the flood irrigation system that is still managed by hand. In Africa, the bulk of cereal crops is grown on small plots surrounded by land occupied by wild plants, of which many species are host plants of cereal stemborers (Mohamed, Khan, Overholt & Elizabeth, 2004).

In order to determine moth flight patterns, *Busseola fusca* and *Sesamia calamistis* moth flights were monitored from November 2004 – October 2006 (Chapter 2). Omni-directional traps were used and mounted close to or in maize fields. Sex pheromones dispensers were suspended from the roofs of these traps and traps were monitored at weekly intervals. *Chilo partellus* sex pheromones

were also used but no moths were trapped, indicating that the pheromone was ineffective. The mean number of moths trapped / week was calculated for each species. The larval population dynamics and species distribution of the three stemborers and their natural enemies on maize in farmers' fields were monitored between June 2005 and March 2006 (Chapter 3). The incidence of stemborer damaged plants was determined and destructive sampling done to determine stemborer species distribution every four to six weeks between October 2004 and March 2006. Infested plants from different age groups were collected from different fields for dissection where after stemborer larvae, pupae and their parasitoids were reared through in petri-dishes and identified. In another survey done to determine if Napier grass would be effective as a trap crop for stemborers when planted as long contour strips along two sides of maize fields, stemborer infestation levels were determined in different fields and compared to fields without Napier grass trap crops (Chapter 4). Different maize fields were sampled once during the months of May, July, August, October and November 2005 where after plants were dissected to determine the species composition of control fields and fields surrounded by Napier grass.

A total of 2413 larvae were collected which was reared through to adults (Chapter 3). *Busseola fusca*, *S. calamistis* and *C. partellus* larvae were observed in mixed populations in the same planting as well as individual plants. Similar observations were made by Bate, Van Rensburg & Giliomee, (1991) and Van Rensburg, Walters & Giliomee (1988) in the Highveld region of South Africa. Mixed species composition within the same planting complicates insecticide applications, due to the fact that registered insecticides for each species differ in terms of control measures. Effective chemical control of mixed stemborer populations is difficult and, as a possible solution to this problem, the development of an economic threshold model to allow for co-existence of species in varying proportions has been suggested (Bate, Van Rensburg & Giliomee, 1991; Van Rensburg, Walters & Giliomee, 1988).

In southern Africa, stemborer infestation levels range between 30 – 70 % in fields of subsistence farmers where no chemical control action is taken compared to less than 30 % on commercial farms where chemical control is applied to control infestations (Sithole, 1987). Integrated pest management may be sufficient in reducing pest populations and crop damage to below economic threshold levels in South Africa (Kfir, 1990). According to Bate & Van Rensburg (1992) the economic threshold level (ETL) for *C. partellus* was determined as 40 % plants with visible whorl

damage symptoms and Seshu-Reddy & Sum (1991) found the economic injury level (EIL) varied between 0.66 – 1.41 larvae / plant for *C. partellus*. At Tshiombo much higher numbers of larvae / plant (> 2.97) were recorded although the incidence of damaged plants, on which an ETL is based, ranged between 7 – 30 %. This low incidence of visual damage and high larval infestation levels especially for *C. partellus* showed that visual symptoms of stemborer damage are not always the best predictor of larval infestations / plant. The infestation levels of *C. partellus* at Tshiombo can therefore be considered to be relatively low and possibly not of economic importance as the number of larvae / plant are dependant on plant variety and age.

This relatively low incidence of damaged plants and seemingly low importance of stemborers could only be ascribed to alley cropping, crop rotation and soil cultivation practices, which destroy most plant residues which may harbour stemborers. Crops are regularly rotated with other crops like groundnut and sweet potato. Direct treatments for stemborer damage include the application of fire ash in plant whorls. Although *C. partellus* may not be of economical importance its numbers may still increase at Tshiombo. *Chilo partellus* is reported to displace other stemborer species due to the fact that it is a highly competitive coloniser. It has been observed to gradually displace *B. fusca* from maize in South Africa (Kfir, Overholt, Khan & Polaszek, 2001). Results indicated that *C. partellus* can be considered the most important stemborer species at Tshiombo since it made up between 75 – 99 % of the total stemborer population over the whole sampling period (Chapter 3). The continuous presence of host plants and the warm climate in sub-tropical low-altitude areas facilitate the continuous development of *C. partellus* all-year round.

All larval stages of *C. partellus* were present throughout the year which indicated that conditions were always suitable for larval development. The low incidence of stemborer infestation and activity throughout the year can also be ascribed to the continuous planting of maize in a polyculture system, which is made possible by irrigation at Tshiombo. The fluctuation in stemborer numbers was synchronised with the larval size distribution. An increase in the proportion of young larvae (small and medium larvae) was associated with an increase in the incidence of the percentage infested plants during both the pre- and post-flowering periods. These overlapping generations of *C. partellus* (Kfir, 1998) resulted in infestations throughout the growing season, and according to Kfir (1998), may render insecticide applications to be unsatisfactory. Currently a granular insecticide is applied on young plants and chemical sprays are applied occasionally. These

granules are applied in the whorl where it kills small larvae. Timing of insecticide application is crucial, as sprays are only effective in controlling the young larvae (Kfir *et al.*, 2001). Older larvae penetrate stems of host plants and become inaccessible to pesticides. Although chemical control is effective against stemborers this practice is not feasible for small-scale farmers in Africa (Bonhof, Overholt, Van Huis & Polaszek, 1997). Chemical control is unrealistic in terms of high costs, is time consuming to apply and there is a lack of advisory services. However, the minimum use of chemicals can be integrated with other control measures like biocontrol and intercropping to manage these pests.

On the Highveld region of South Africa, where winter temperatures decrease to levels that are not suitable for larval development, no stemborer activity is noticed during the winter months (Annecke & Moran, 1982; Van Hamburg, 1987) and moth activity only commences after larval diapause is terminated (Van Rensburg, Walters & Giliomee, 1985; 1987). Contrary to the pattern of zero *B. fusca* activity observed in commercial maize production systems in the western and eastern maize producing areas of South Africa (Van Rensburg *et al.*, 1985), *B. fusca* activity was noticed throughout the year and especially during the winter months at Tshiombo. However, no larvae were present in aboveground plant parts during certain periods of the year which might be an indication of diapause. Although temperature makes a minor contribution to diapause initiation (Van Rensburg, Walters & Giliomee, 1987) winter is usually the period when *B. fusca* and *C. partellus* naturally diapause as mature larvae in dry stalks (Kfir, 1988; 1991). The absence of *B. fusca* larvae during certain months can be ascribed to either diapause, which may be initiated by plant age, or composition (Van Rensburg, Walters & Giliomee, 1987). The *B. fusca* flight pattern showed two distinct peaks, the first during December/January and the second during October (Chapter 2). During the pre- and post-flowering period both *B. fusca* and *S. calamistis* larval numbers were low compared to *C. partellus*. The increased larval infestation levels observed during January fall within the main maize producing period at Tshiombo. This peak in larval numbers on pre-flowering plants coincided with increased moth catches during January. Moths flying between three and five weeks after emergence make the most important contribution to the total infestation in a planting and based on the egg-laying pattern, this key period was identified as between four and six weeks after emergence (Van Rensburg, Walters & Giliomee, 1987). Plantings should only be monitored for infestations during the egg-laying period, three to six weeks after plant emergence. This information can be used to determine the timing of pest management

activities (Van Rensburg *et al.*, 1987). However, at Tshiombo, because of the large scale overlapping of generations of all stemborer species, monitoring for eggs is not practical and curative control measures should be based on scouting for whorl damage symptoms.

Prior to this study no information existed on *S. calamistis* moth flight patterns in South Africa. During the start of December and at the end of January increased numbers of moths were observed showing two peaks for *S. calamistis* which fall in the main maize producing period. This pest is distributed all-over South Africa and numbers outside coastal areas are low (Van den Berg & Drinkwater, 2000). In contrast larval numbers found at Tshiombo were relatively high and *S. calamistis* made up a significant proportion of the population during August, May and October. These numbers could be ascribed to the subtropical environment at this irrigation scheme and the abundance of young and old plants during all seasons.

In the Napier grass habitat management system 83 % (10/12) of fields during the whorl stage had lower incidences of damaged plants compared to control fields, but only six (50 %) of these were significantly lower ($p < 0.05$) (Chapter 4). The mean percentage damaged plants for trap and control fields showed no consistent patterns in infestations due to means varying between fields with low incidence of stemborer damage and fields which had high incidences of damage. The lower incidence of infestation in blocks surrounded by Napier grass showed that this method of pest control can be effective under certain conditions. During the pre-flowering period *C. partellus* was the dominant species with proportions of between 67 – 100 % of the population in the trap crop fields and 88 – 100 % in the control fields. High proportions of *C. partellus* were always present in control fields with statistically significant differences between trap and control damaged fields. *Busseola fusca* could only be observed in very low numbers with a proportion of less than 17 %. *Busseola fusca* and *S. calamistis* were always absent in control fields during the pre-flowering stage ($p < 0.05$) except in one case. In maize plants with Napier grass on contours *C. partellus* was always present and in high proportions (> 95 %) when statistically significant differences were observed between the incidence of damage in trap and control fields (Chapter 4). Because of its non-determinant growth pattern and, thereby, continuous availability of plant parts suitable for oviposition, *Pennisetum purpureum* (Schumacher) is a much more stable habitat for both pests and natural enemies than maize (Ndemah, Schulthess, Poehling, Borgemeister & Goergen, 2001). The reduced incidence of damage could be ascribed to moths laying eggs on trap

plants subsequently reduced egg load of moths that do infest the maize after encountering the trap crop (Ndemah, Gounou & Schulthess, 2002). Napier grass bordering maize fields on two contours should be expanded further on the irrigation scheme. This pest management technique together with the introduction of a natural enemy like *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) against the dominant *C. partellus* could suppress stemborer numbers.

Larval parasitoids were active all-year round and the most abundant parasitoid was *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) which was reared from 85 % of parasitized larvae. Kfir (1990) observed that *Co. sesamiae* was the most abundant parasitoid of *C. partellus* and reared it from 93 % of parasitized larvae at Brits in the North-West Province. *Cotesia sesamiae* parasitised larvae of all three stemborer species and had a mean of 10 % over the study period. The highest larval parasitism level recorded during January was on *C. partellus* larvae (34 %) but the average parasitism level during the year was only 8 % with mean percentages below 1 % for *S. calamistis* and *B. fusca*.

Classical biological control is an option as part of an IPM strategy for *C. partellus*, especially in the sub-tropical areas of the Limpopo Province. The introduction of an exotic parasitoid like *Co. flavipes* will encounter both old- and new-association hosts when colonising a new area. Because of the economic importance of *C. partellus* and its status as an introduced pest, it has been a target of classical biological control attempts in South Africa (Kfir, 1994). *Cotesia flavipes* may be the most suitable in future release as a biocontrol agent at Tshiombo. In a study in Kenya *Co. flavipes* was observed to have higher searching ability and attacked more stemborer larvae than *Co. sesamiae* (Sallam, Overholt & Kairu, 1999). *Cotesia flavipes* also out-competed *Co. sesamiae* when *C. partellus* was parasitized by both species (Sallam, Overholt & Karui, 1999). *Cotesia flavipes* has a wide host range and attacks stemborers in large-stemmed grasses like maize (Kfir, Overholt, Khan & Polaszek, 2001). Wiedenmann & Smith (1993) demonstrated that, even at low densities, *Co. flavipes* was able to successfully locate stemborer hosts. The probability of establishment and the level of suppression of the stemborer complex may depend not only on the old host/parasitoid relationship (e.g. *Co. sesamiae* and *S. calamistis*) but also on the capability of the new relationship (e.g. *Co. sesamiae* and *C. partellus*) (Kfir, Overholt, Khan & Polaszek, 2001). As only *Co. sesamiae* was observed at Tshiombo a higher mortality rate of all three stemborer species can be attained if an exotic parasitoid like *Co. flavipes* is released at this scheme. At

Tshiombo only six *Dentichasmias busseolae* (Heinrich) (Hymenoptera: Ichneumonidae) pupal parasitoids was recovered and only from *C. partellus* and *B. fusca*.

Because crop plants and wild hosts exist in the same area, a prerequisite for development of a pest management strategy is an understanding of the multiple interactions among cultivated crops, wild hosts, various stemborer species and natural enemies, all of which may affect the dynamics of pest populations and pest status (Mohamed *et al.*, 2004). The fact that plants were sampled destructively during this investigation and that different fields were monitored at each sampling period make it impossible to give precise information on reinfestation patterns. Plants at different growth stages were always present and made it difficult to measure infestations compared to monoculture systems. Damage potential and degree of damage may be important in future studies to apply ETL's so that pesticides can be applied accordingly in maize fields. The integrated pest management approach may only be viable if adequate advisory services are implemented to inform farmers about dealing with stemborers on a sustainable level.

5.1 References

- AMPOFO, J.K.O.** 1988. Some observations on *Chilo partellus* (Swinh.) (Lepidoptera: Pyralidae) developmental biology under fields and laboratory conditions. *Insect Sci. Appl.* 9: 271-274.
- ANNECKE, D.P. & MORAN, V.C.** 1982. Insects and mites of cultivated plants in South Africa. *Butterworths & Co.* Durban, South Africa. 383 pp.
- BATE, R. & VAN RENSBURG, J.B.J.** 1992. Predictive estimation of maize yield loss caused by *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in maize. *S. Afr. J. Plant Soil* 9: 150-154.
- BATE, R., VAN RENSBURG, J.H. & GILIOME, J.H.** 1991. Distribution and occurrence of the stem-borer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) on maize in South Africa. *J. Afr. Zool.* 105: 11-15.
- BONHOF, M.J., OVERHOLT, W.A., VAN HUIS, A. & POLASZEK, A.** 1997. Natural enemies of cereal stemborers in east Africa: A review. *Insect Sci. Appl.* 17: 19-35.
- KFIR, R.** 1988. Hibernation by the lepidopteran stalk borers, *Busseola fusca* and *Chilo partellus* on grain sorghum. *Entomol. Exp. Appl.* 48: 31-36.
- KFIR, R.** 1991 Duration of diapause in the stem borers, *Busseola fusca* and *Chilo partellus*. *Entomol. Exp. Appl.* 61: 265-270.
- KFIR, R.** 1990. Parasites of the spotted stalk borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in South Africa. *Entomophaga* 35: 403-410.
- KFIR, R.** 1994. Attempts at biological control of the stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae), in South Africa. *Afr. Entomol.* 2: 67-68.
- KFIR, R.** 1998. Maize and grain sorghum : southern Africa, pp. 333-347. In : Polaszek, A., ed. *African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control.* CAB International. Wallingford, UK. 530 pp.

KFIR, R., OVERHOLT, W.A., KHAN, Z.R. & POLASZEK, A. 2001. Biology and management of economically important Lepidopteran Cereal Stem Borers in Africa. *Ann. Rev. Entomol.* 47: 701-31.

MOHAMED, H.M., KHAN, Z.R., OVERHOLT, W.A. & ELIZABETH, D.K. 2004. Behaviour and biology of *Chilo partellus* (Lepidoptera : Pyralidae) on maize and wild gramineous plants. *Internat. J. Trop. Insect Sci.* 24 : 287-297.

NDEMAH, R., SCHULTHESS, F., POEHLING, M., BORGEMEISTER, C. & GOERGEN, G. 2001. Natural enemies of Lepidopterous borers on maize and elephant grass in the forest zone of Cameroon. *Bull. Entomol. Res.* 91: 205-212.

SALLAM, M.N., OVERHOLT, W.A. & KAIRU, E. 1999. Comparative evaluation of *Cotesia flavipes* and *C. sesamiae* (Hymenoptera: Braconidae) for the management of *Chilo partellus* in Kenya. *Bull. Entomol. Res.* 89: 185-191.

SESHU REDDY, K.V. & SUM, K.O.S. 1991. Determination of economic injury level of the stem borer, *Chilo partellus* (Swinhoe) in maize, *Zea mays* L. *Insect Sci. Appl.* 12 : 269-274.

SITHOLE, S.Z. 1987. Maize insect pests in Zimbabwe. Toward Insect Resistant Maize for the Third World. *Proc. Int. Symp. Methodol. Developing Host Plant Resistance Maize Insects.* CIMMYT. Mexico: Mexico City. Pp. 286-88.

VAN DEN BERG, J. 2006. Oviposition preference and larval survival of *Chilo partellus* (Lepidoptera: Pyralidae) on Napier grass (*Pennisetum purpureum*) trap crops. *Int. J. Pest Manag.* 52: 39–44.

VAN DEN BERG J., DE BRUYN, A.J.M & VAN HAMBURG, H. 2006. Oviposition preference and survival of the maize stem borer, *Busseola fusca* (Lepidoptera: Noctuidae) on Napier grasses (*Pennisetum* spp.) and maize. *Afr. Entomol.* 14: 211–218.

VAN DEN BERG, J. & DRINKWATER, T.W. 2000. Pink stemborer. *Plant Protection series no. 20*. ARC Grain Crops Research Institute, Private Bag X1251, Potchefstroom, 2520, South Africa.

VAN HAMBURG, H. 1987. A biological control approach to pest management on grain crops with special reference to the control of stalkborers. *Tech. Commun., Dep. Agric. Water Supply, Rep. S. Afr.* 212: 52-55.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1985. Geographical variation in the seasonal moth flight activity of the maize stalkborer, *Busseola fusca* (Fuller), in South Africa. *S. Afr. J. Plant Soil* 2: 123-126.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.M. 1987. Ecology of the stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *Bull. Entomol. Res.* 77: 255-269.

VAN RENSBURG, J.B.J., WALTERS, M.C. & GILIOMEE, J.H. 1988. Response of maize to levels and times of infestation by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). *J. Entomol. Soc. sth. Afr.* 51: 283-291.

WIEDENMANN, R.N. & SMITH, J.W. 1993. Functional response of the parasite *Cotesia flavipes* (Hymenoptera: Braconidae) at low densities of the host *Diatraea sacharalis* (Lepidoptera: Pyralidae). *Environ. Entomol.* 22: 848-858.