ECOLOGY AND BIOLOGICALLY BASED MANAGEMENT OF CEREAL STEMBORERS ON MAIZE AND SORGHUM IN THE AMHARA STATE OF ETHIOPIA

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other University or any other award.

Melaku Wale Ferede — Date: 26.07.06

We as Kenyatta University and ICIPE's supervisors confirm that the work reported in this thesis was carried out by the candidate under our supervision. The thesis was examined and we approved for its final submission.

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DEDICATION

I dedicate this work to the late my father, Mr Wale Ferede Wondim, who cultivated me in school from childhood, and who passed away before he saw me wind up my doctoral thesis.

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ABSTRACT

A series of studies were conducted in an attempt to establish baseline data on the importance and geographic distribution of stemborers and to determine key interactions among a whole range of factors, abiotic – i.e., soil fertility - and biotic – i.e., host plants, intercrops, planting time, borer species, and beneficial organisms, in the stemborer ecosystem in the Amhara State of Ethiopia. These data are prerequisites for devising environmentally sound sets of stemborer management technologies. Thus, distribution of stemborers and natural enemies, the effect of different levels of fertilization on stemborers and associated yield loss (by exclusion and inclusion of borers by using insecticide), effects of indigenous cropping systems, and the effect of planting time on the borer dynamics were studied from 2003 to 2004 in the cool-humid western and semi-arid eastern regions of the Amhara state. The mixed model and the general linear model procedures of SAS, stepwise regression, correlation, logistic regression, and dispersion analyses were employed in data analysis.

Three lepidopterous borer species on maize and sorghum, i.e., *Chilo partellus, Busseola fusca, Sesamia calamistis,* and on sorghum one coleopterous borer, *Rhynchaenus niger*, were found. In eastern Amhara, the species composition was 91% *C. partellus*, 8% *B. fusca* and 1% *S. calamistis*. In western Amhara, only *B. fusca* was recorded on sorghum, whereas on maize 61% was *B. fusca* and 39% *S. calamistis*. Borer density generally increased with crop growth stage. *C. partellus* parasitism by *Cotesia flavipes*, which occurred only in eastern Amhara, varied among districts ranging from a mean of 5% to 39%. In western Amhara, unidentified nematodes parasitised medium sized *B. fusca* larvae during the wet months. Borer damage was generally higher in eastern Amhara. Taylor's power law equations showed aggregated distribution for *C. partellus* and *B. fusca* larvae.

Response to N was observed in western Amhara. Percentage leaf nitrogen content was positively related to N fertilizer dosage. In general, pest density, parasitism and plant growth and borer damage variables increased with crop growth stage. On sorghum, in western Amhara, increasing levels of N fertilizer also tended to increase pest density, plant growth and damage variables, and in eastern Amhara, it increased larval parasitism by *C. flavipes*. Likewise, sorghum yields increased by up to 74% due to fertilization, and although grain losses due to borers across locations were between 19 and 49%, the losses decreased linearly from 49% at no fertilizer level to 36% at the highest N level. In maize, although the trend is similar, there were no discernable trends for pest infestation and yield losses due to the low borer densities. Sorghum yields were positively related to plant growth variables (stem diameter, plant height) and negatively to borer numbers and holes bored. In eastern Amhara, the response to fertilizer input of pest, damage and yield was low due to the higher soil fertility and probably low precipitation.

Results of intercropping systems indicated that in western Amhara mustard (*Brassica carinata* Braun) (Cruciferae) had lower borer density (*B. fusca*) and damage levels. Borer density was higher at the vegetative than other growth stages. Yield was generally higher on the intercropped plots than in plots with sole maize, and was positively related to plant growth parameters and negatively to stem tunneling. In eastern Amhara, intercrops except sweet potatoes seemed to decrease *C. partellus* numbers and their damage.

Results of planting time indicated that *B. fusca* density and damage decreased with delay in planting time. It increased with growth stage until grain filling, but declined at harvest. *R. niger* borers were also observed. Parasitism of stemborers by nematodes was higher, though not significant on the mid-season planted plots. Grain yields were higher on the mid planted crop; this was partly due to bird attack on early-planted plots and lack of sufficient moisture on the late-planted crops. Stepwise regressions showed that yield was related positively to basal diameter, and negatively to borer density, number of holes, internode damage, peduncle damage, and tunneling. Thus, early planting may be practiced in areas of short rainy season, regardless of higher borer damage, while there is ample reason to stagger planting in areas of long rainy-season. However, studies specific to the major agro-ecologies is required for complete recommendation.

In summary, the present study showed that the distribution, species composition and economic importance of stemborers vary with regions in the Amhara state, calling for specific strategy for future management. In western Amhara, on sorghum on which borer density and damage were high, increasing soil nutrients via fertilizer application leads to an increase in borer attack, but also to improved plant vigor, resulting eventually in a net benefit for the plant and the grain yield; while, mustard intercropping seems to be a dynamic tradition which helped to keep stemborers away from the otherwise would-be stemborer hot spot areas of western Amhara and, which can also be a potential component of stemborer management in areas where it is not practiced. The practical application aspects of the results and further researchable areas of intercropping systems are discussed.

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ACRONYMS AND ABBREVIATIONS

ai	Active ingredient
ANOVA	Analysis of variance
ARARI	Amhara Regional Agricultural Research Institute
ARPPIS	African Regional Post-graduate Program in Insect Science
BOA	Bureau of Agriculture
BOA ANRS	Bureau of Agriculture Amhara National Regional State
CABI	Commonwealth Agricultural Bureaux International
CACC	Central Agricultural Census Commission
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Authority (Ethiopia)
CTA	Technical Centre for Agricultural and Rural Cooperation
DAP	Dia-ammonium Phosphate
DDT	Dichloro-diphenyl-trichloroethane
DF	Degrees of freedom
EARO	Ethiopian Agricultural Research Organization
e.c.	Emulsifiable concentrate
E.C.	Ethiopian Calendar
ECSA	Ethiopian Central Statistical Authority
ENSIA	Ethiopian National Seed Industry Agency
ESE	Ethiopian Seed Enterprise
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GPS	Global Positioning System
Ha	Hectare

IAR	Institute of Agricultural Research (Ethiopia)
ICIPE	International Center of Insect Physiology and Ecology
KARI	Kenya Agricultural Research Institute
LSMEANS	Least squares means
Min T	Mean minimum temperature ^oC
Max T	Mean maximum temperatures ^oC
ml	milliliter
PEDB	Planning and Economic Development Bureau (Amhara State)
PROC GLM	General linear model procedure of SAS
RF	Total monthly rainfall (mm)
RH	Relative humidity (%)
SAS	Statistical Application System
SE	Standard error
SIDA	Swedish International Development Agency
SNK	Student Newman-Keuls multiple range test
SNNPR	Southern Nations Nationalities and Peoples Region (Ethiopia)
USAID	United States of America International Development

CHAPTER ONE

GENERAL INTRODUCTION

Maize and sorghum are the most important grain crops grown by small scale and commercial farmers in Africa. In 2002 alone, over 42 million tons of maize and 20 million tons of sorghum were produced (FAO, 2003). Currently, in Ethiopia, these crops are grown on an estimated area of 2.4 million hectares producing 4.3 million tones of grain (CSA, 2000; CACC, 2003), contributing about 41% of the country's annual grain production. The Amhara State contributes more than a quarter of this produce. The production of sufficient food for farmers in drought-prone areas of Ethiopia is a major challenge. Therefore, improving the production of maize and sorghum crops is the only way out from recurrent famine in the drought-stricken parts of the country. To that end, high priority is given to the production of maize in the strategy for food self-sufficiency in the country.

Maize thrives well in cool and wet intermediate altitudes, 1500-2000 m above sea level, while sorghum has a tremendous genetic diversity in Ethiopia and is the dominant crop in the lowlands (< 1500 m a.s.l.) where drought and poor harvest are common (Birhane, 1977). It is second to *tef* (*Eragrostis tef* Zucc. Trotter) (Poaceae) as source of *injera*, the Ethiopian national dish. The Amhara state is the second biggest producer state of both maize and sorghum in Ethiopia (CACC, 2003). Despite their importance, these crops suffer great yield losses due to stemborers and other insect pests. Among the insect pests that attack sorghum and maize in Africa, the lepidopterous stemborers are the most injurious (Kfir *et al.*, 2002). In Ethiopia, three species of stemborers, namely *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Sesamia calamistis* Hampson

(Lepidoptera: Noctuidae) attack maize and sorghum (Assefa, 1985). Two other species, i.e., *Sesamia nonagrioides botanephaga* Tams and Bowden (Lepidoptera: Noctuidae) and *Rhynchaenus niger* (Horn) (Coleoptera: Rhynchophoridae) were reported recently (Emana, 2002). The exotic parasitoid *C. flavipes* Cameron was reported to have occurred in some parts of Ethiopia (Emana *et al.*, 2001). Since its introduction in 1993 into Kenya (Overholt *et al.*, 1994a) by the International Centre of Insect Physiology and Ecology (ICIPE), it has successfully reduced stemborers by 60% and increased yields by 10-15% in coastal Kenya (Overholt *et al.*, 1997; Zhou *et al.*, 2001). It is believed to have invaded Ethiopia probably from Somalia, where it was later introduced in 1997 (C. Omwega, ICIPE, Kenya, pers. comm.).

In the Amhara State, though little is known of the distribution and economic importance of stemborers and their natural enemies, stemborers are regarded as the major pests of maize and sorghum (BOA, 1999). Crop losses reported in Ethiopia vary with locations, crop species attacked and borer species and it ranges between 15 and 100% (Assefa, 1989; Tadesse, 1989; Gashawbeza and Melaku, 1996; Emana, 1998b). There is hardly any information on the level of crop loss due to stemborers in the Amhara state of Ethiopia (BOA, 1999).

Although insecticides generally have a quick knockdown effect on insects, their efficacy on stemborers, unless they are systemic, is limited since these pests are hidden in the plant. Furthermore, adoption of insecticides is slow due to inconsistent supplies, increasing prices, poisoning risks and environmental pollution (Kfir *et al.*, 2002). Other pest management tactics such as biological control agents, host plant resistance and habitat management could replace pesticides. Currently, attempts are being made to integrate non-pesticide options for the control of insect pests. The effect of cultural practices such as intercropping on stemborers and the introduced and native biological control agents must be assessed in order to guarantee their success (CTA, 1997). Habitat management and/or cultural practices stabilize the habitat maintaining indigenous natural enemies in the otherwise fragile ecosystem (Kfir *et al.*, 2002). Growing cereals with field beans can provide more yield benefits compared to a crop grown alone (Bulson *et al.*, 1990). Several plant species have been identified which could serve as trap or repellent plants in push-pull strategy of stemborer management (Khan *et al.*, 2001). Recent studies in Kenya have indicated the effectiveness of intercropping maize with non-host molasses grass. The volatile agents produced by molasses grass repelled stemborers but attracted foraging *Cotesia sesamiae* (Khan *et al.*, 1997). Most similar studies, however, did not seek to determine the underlying mechanisms behind the effect of intercropping on stemborer population levels (Kfir *et al.*, 2002).

Further, low soil fertility is a major problem in much of the Amhara State (Getachew and Wondimu, 2005) and generally in Ethiopia (Tolessa *et al.*, 2001). Nitrogen fertilization enhances borer development as well as the plant tolerance to borer attack (Archer *et al.*, 1987; Martin *et al.*, 1989; Setamou *et al.*, 1993, 1995; Chabi-Olaye *et al.*, 2005a). Adjusting planting time plays a profound role in borer dynamics and subsequent pest control actions (Kumar, 1984). In addition to scanty knowledge on borer and natural enemies distribution and importance, the efficacy of the whole range of borer management techniques have not been assessed in the Amhara state.

In fact, stemborer management research activities in Ethiopia have been going on in the Rift Valley area, central, eastern and southern parts of the country. This indicates that there exist serious gaps in stemborer research in the country. Some gaps are geographical, like the absence of information from the Amhara State, excepting the limited surveys carried out recently on the distribution of stemborers and their natural enemies (Emana, 2002). The Amhara State is one of the few major grain producing areas in the country, which was largely neglected, though it suffers similar pest problems (Shegaw *et al.*, 1999; Melaku Wale, unpub.). These gaps occur partly because of inadequate funding, poor infrastructure like roads and remoteness of the Amhara state from the traditionally known centres of excellence in the country. The objective of this study was to fill the gap and contribute to food self-sufficiency in the state, and in the country as a whole. Information on the distribution and management practices of stemborers in the Amhara State is a prerequisite for their effective control. The present series of studies, thus, tried to assess the distribution and economic importance of stemborers and their natural enemies in the region, estimate the level of yield loss caused by stemborers as influenced by fertilization, determine the role of an indigenous multiple cropping system, i.e., intercropping, and planting time in stemborer control, as they apply to the Amhara state. The information obtained will serve as a springboard for future research efforts and contribute to the current agricultural extension program in the Amhara State of Ethiopia.

1.1 Rationale and justification

Maize and sorghum are two of the major cereal grain crops grown widely in Ethiopia. Stemborers are listed among the major insect pests of these crops. Control of stemborers in the country has focussed on the use of insecticides, with all their drawbacks. Little stemborer research has been carried out in the Amhara State of Ethiopia. Sustainable control methods such as biological and cultural methods were the least studied and applied due to lack of knowledge of the diversity of the native biological control agents and sustainable management practices. The present study, therefore, intended to investigate the occurrence, distribution and importance of stemborer species and their natural enemies, estimate yield losses and level of borer damage at different nitrogen fertilizer levels, and assess the effect of cropping systems and planting time on stemborers and their biological control agents at ecologically distinct regions.

1.2 Hypotheses

a. Distribution and importance of stemborers and their natural enemies varies with region, ecosystem and host plant.
b. Nitrogen fertilizers enhance both stemborer survival and plant growth but reduce the potential grain yield loss.
c. There is interaction between cropping (intercropping) systems and stemborers and their biological control agents.
d. There is interaction between planting time and stemborers and their biological control agents.

1.3 Objectives of the study

1.3.1 General objective

To investigate species composition, geographic distribution and importance of stemborers and their natural enemies, determine the level of yield loss at various N fertilizer levels and determine efficacy of habitat management practices against stemborers and their effect on stemborers and biological control agents in the Amhara State.

1.3.2 Specific objectives

a. To investigate the geographic distribution and importance of stemborers and their natural enemies on maize and sorghum.

b. To determine the level of grain yield loss caused by stemborers on sorghum and maize at different fertilizer levels.

c. To determine the effect of indigenous intercrops on stemborer infestation and the performance of their natural enemies.

d. To determine the effect of planting time on stemborer infestation and the performance of their natural enemies in western Amhara.

CHAPTER TWO

LITERATURE REVIEW

2.1 Species composition and geographic distribution of stemborers in Africa

Maize and sorghum suffer great yield losses due to pests, the most injurious being the lepidopterous stemborers (Kfir *et al.*, 2002). In Africa, twenty-one economically important lepidopteran stemborers of cereals, including 7 noctuids, 2 pyralids, and 12 crambids have been listed (Maes, 1998). Seven of these attack rice, and one is a pest of pearl millet in the Sahelian region. The noctuids, *Busseola fusca* and six *Sesamia* spp. are considered economically important. The largest and most injurious group of 12 species is the crambids, with a majority of seven species belonging to *Chilo* spp. Zincken. In South Africa, *B. fusca* and *C. parterllus* are the only important stemborers of maize and sorghum (Kfir, 1998). In East Africa, *C. partellus*, *C. orichalcociliellus*, *E. saccharina* (Walker), *B. fusca*, and *S. calamistis* are mentioned as important and widely distributed stemborers of maize and sorghum (Seshu Reddy, 1998). In West Africa, *B. fusca*, *S. calamistis* and *E. saccharina* (Bosque-Perez and Schulthess, 1998) and in the Sahelian zone on pearl millet *Coniesta ignefusalis* dominate (Harris and Youm, 1998).

Two of the economically important cereal stemborers in Africa are the introduced species, i.e., *C. partellus* and *C. sacchariphagus* (Kfir *et al.*, 2002). The former originated from Asia and invaded Africa sometime before 1930, and it was first recorded in 1930. The second report came from Tanzania 20 years later (Duerden, 1953). The distribution of *C. partellus* includes Ethiopia, Sudan, Somalia, Kenya, Tanzania, Uganda, Mozambique, South Africa, Swaziland, Lesotho, Zimbabwe, Zambia, Malawi, and Botswana (Nye, 1960; Ingram, 1983; CABI, 1989).

Using Geographic Information System (GIS) tools, Overholt *et al.* (2000) predicted the eventual distribution of *C. partellus* in Africa based on climate data at locations where it was known to occur and then extrapolating to other locations with similar climates. The prediction included several countries in south-western Africa and West Africa where this species is not yet known to occur.

B. fusca and *Sesamia* spp. occur throughout sub-Saharan Africa (Ingram, 1983). *S. calamistis* is the most widely distributed and economically important of the *Sesamia* spp., but several others, including *S. cretica*, which occurs in Somalia, Sudan, and Ethiopia, and *S. nonagrioides botanephaga*, which is found in both East and West Africa, are also important (Kfir *et al.*, 2002).

In Africa, the noctuid borers prevail over the pyralid borers, which are predominant in the Americas, Asia and Europe (Alejandro, 1987). The pest status of *B. fusca* varies by region. In East and southern Africa, it is a pest at higher altitudes (>600 m) (Nye, 1960; Sithole, 1989), but in West Africa, it occurs from sea level to > 2000 m (Tams and Bowden, 1953), but it is primarily a pest in the dry savanna zone (Harris, 1962). *Chilo zacconius* Blezynski, *Maliarpha separatella* Ragonot and *S. calamistis* are considered to be the most economically important stemborers of rice in West Africa (Akinsola and Agyen-Sampong, 1984). *M. separatella* is the only rice borer that has a widespread distribution in sub-Saharan Africa, including the Comoro islands and Madagascar (Kfir *et al.*, 2002). *Chilo sacchariphagus* is a serious pest of sugarcane in the Indian Ocean islands, which probably was introduced from Sri Lanka or Java with sugarcane around 1850 (Kfir *et al.*, 2002). Recently, this species is reported on sugarcane in Mozambique (Kfir *et al.*, 2002). Table 1.1 shows the list of important borer species in Africa (Kfir *et al.*, 2002).

Table 2.1 Important cereal stemborer species in Africa and the Indian Ocean islands, their distributions, and major cultivated host plants

Family	Species	Distribution	Host plants
Crambidae	*Chilo partellus*	Eastern and southern Africa	Maize, sorghum
	Chilo orichalcociliellus	Coastal eastern Africa, Malawi, Madagascar, South Africa, Zimbabwe	Maize, sorghum
	Chilo aleniellus	West and Central Africa	Rice, maize
	Chilo sacchariphagus	Indian Ocean islands, Mozambique	Sugarcane
	Chilo zacconius	West Africa	Rice
	Chilo diffusilineus	Tropical Africa	Rice
	Coniesta ignefusalis	Sahelian Africa	Pearl millet
	Scirpophaga spp.	West Africa	Rice
Noctuidae	*Busseola fusca*	Sub-Saharan Africa	Maize, sorghum
	Sesamia calamistis	Sub-Saharan Africa	Maize, sorghum, rice
	Sesamia nonagrioides botanephaga	West Africa, Sudan	Maize, rice, sorghum, sugarcane
	Sesamia cretica	Northeast Africa	Sorghum, maize
Pyralidae	*Eldana saccharina*	Sub-Saharan Africa	Sugarcane, maize, rice
	Maliarpha separatella	Sub-Saharan Africa, Indian Ocean islands	Rice

Source: Kfir *et al.* (2002)

2.2 Species composition and geographic distribution of stemborers in Ethiopia

Assefa (1985, 1990) reported three species of lepidopterous stemborers in Ethiopia, namely *B. fusca*, *C. partellus* and *S. calamistis*. The first two are the major ones, whereas *S. calamistis* is sporadic (Assefa, 1991). *Busseola fusca* is dominant in higher altitudes (1160-2500 m a.s.l.) and cooler areas of the country whereas *C. partellus* is the most important species in warm and low altitudes (510-1700 m a.s.l.); *S. calamistis* is recorded at lower to medium altitude areas (1200-1750 m a.s.l.) (Tessema, 1982; Assefa, 1985; Birhane, 1985; Assefa *et al.*, 1989; Abraham *et al.*, 1993). *B. fusca* is the most important stemborer species in western Ethiopia followed by *C. partellus* and *S. calamistis* (Assefa, 1985; Emana, 2002). *B. fusca* is also important in northwestern Ethiopia.

Chilo partellus is dominant in the lowlands of southern, eastern and northeastern Ethiopia (Tessema, 1982; Assefa, 1985). It is the major pest of sorghum in the Pawe (warm humid) area of northwestern Ethiopia (Abadi *et al.*, 1994). It is an exotic species, originating from India, first reported in Malawi in 1930, and later spread to East Africa and eastern Ethiopia (Sithole, 1989).

S. calamistis occurs in western, southern, and eastern Ethiopia, but it is generally a minor pest (Assefa, 1985). It is more or less restricted to the Rift Valley and was first reported in the Asabot plains of eastern Ethiopia in 1973 (Tessema, 1982).

B. fusca is the major stemborer species in most of western Amhara State, while *C. partellus* dominates the eastern part of Amhara. Assefa (1985) suggests that temperature, rather than altitude, determines distribution of cereal stemborers.

2.3 Population dynamics of stemborers

In East Africa, *C. partellus* may undergo five or more successive generations in one cropping season; in cold or dry conditions it may enter diapause (Overholt *et al.*, 2001). In South Africa, *C. partellus* generations overlapped, and all developmental stages were observed throughout most of the summer (November to March), and the borer completed two and half generation per season, i.e., the first generation occurred during October-November on ratoon crop, and one and half generations on the commercial crop (Kfir, 1992).

Two to three generations of *B. fusca* are reported in most locations; in humid areas up to four (Harris and Nwanze, 1992). First generation adults emerge from diapausing larvae of the previous crop season, with moth flights occurring a few weeks after rains began, when maize or sorghum crops are 3-5 weeks old. In West Africa, two generations of *B. fusca* are reported on sorghum although later studies showed that it could increase to three generations (Harris, 1962). In South Africa, the number of generations of *B. fusca* increases from 2 in the east to 3 in the west (van Rensburg *et al.*, 1985). Three generations of *B. fusca* were reported per year in Awassa area of southern Ethiopia (Assefa, 1989).

2.4 Host plants of stemborers

Stemborers must have evolved in association with grasses, in which the specialised habit of boring into stems has developed (Harris and Nwanze, 1992). Indigenous African grasses such as *Sorghum verticilliflorum* (Steud) Piper including *Sorghum arundinaceum, Pennisetum purpureum* Schum, *Panicum maximum* Jacq, *Hyparrhenia rufa* Nees (Stapf), *Rottboellia exaltata* (L.), and *Phragmites* sp. are recorded to be hosts of *B. fusca.* The original host might have been *Sorghum* or *Pennisetum.* The main crop hosts are maize and sorghum, and, to a lesser extent, pearl millet, finger millet and sugarcane. Maize and sugarcane are not native to Africa. In Kenya, *C. partellus*, *B. fusca* and *S. calamistis* have been recorded on 24 wild plants (Polaszek and Khan, 1998).

Recently, Emana (2002) recorded 16 wild hosts of stemborers in Ethiopia; *Sorghum verticilliforum* (Steud) and *Hyparrhenia rufa* (Nees) Stapf were the most common hosts of stemborers. Elephant grass (*Pennisetum purpureum*) and wild sorghum (*Sorghum verticilliflorum*) were identified as potential wild hosts of *B. fusca* in terms of larval development and survival (Assefa, 1988a). Elephant grass, cat's tail and wheat are also hosts of *B. fusca* (Adhanom and Abraham, 1986). Recently, finger millet (*Eleusine coracana* Gaertn) and wheat (*Triticum* spp.) have been observed being seriously damaged by *B. fusca* in the field in Ethiopia (Melaku Wale, pers. obs.). *B. fusca* managed to complete its life cycle in finger millet, a common cultivated cereal crop in the Amhara state of Ethiopia, as well as the main host maize, but not on wheat (Amsalu Debebe, unpub.). This is due to high fertilizer application, which made finger millet plants thick enough to support larvae. Wheat could only support early instars while the pest completes its life cycle on finger millet (Amsalu Debebe, unpub.).

2.5 Stemborer management practices

2.5.1 Chemical control

Insecticides are used more on pests of cash crops than crops such as sorghum and maize. High costs, difficulty of application and timing, their unavailability in rural areas and scarcity of water for sprays in semi-arid areas discourage their widespread use (Nwanze and Mueller, 1989). Studies have been carried out to determine the relative efficacy of different chemicals in Africa. The earliest practical use of insecticides for the stemborer control was reported from South Africa. In the 1950s, DDT at 22.4 kg ha^{-1} was successfully used against stemborers in Ghana (Bowden, 1956) and in Uganda (Coaker, 1956).

Subsequent studies showed that a single dose of carbofuran at 1.0-2.5 kg ha^{-1} applied to the planting furrows of maize in South Africa and in Nigeria gave good control (Walters, 1975). Granular dusts of endosulfan, carbaryl, malathion, or fenvalerate in leaf whorls were reported to control *B. fusca* effectively (Whitney, 1970; Adesiyun, 1986). In Africa, the use of insecticides will form a vital component of the stemborer control in the emerging large-scale (commercial) farms (Harris and Nwanze, 1992).

In Ethiopia, screening of insecticides, timing and frequency of application for stemborer control has been going on for a considerable time. In studies conducted in the 1970s, two applications of DDT dust or three applications of carbaryl or endosulfan gave good control of *B. fusca* at Awassa (Assefa, 1982). Recently, application of cypermethrin granules, cypermethrin and endosulfan dust gave significantly better yield than application of DDT (Assefa, unpub.). At Ambo, carbofuran (4.4 kg a.i./ha), decamethrin (12.5 ml a.i./ha) and cypermethrin (16 ml a.i./ha) gave promising results (Girma and Fantahun, 1991). Also carbofuran, trichlorfon, endosulfan and diazinon were effective at Awassa and Bako (IAR, 1983). At Nazareth and Zewai, cyhalothrin 5 EC applied at a rate of 16 g a.i./ha 45 days after crop emergence (DAE) gave the best control (IAR, 1990; Gashawbeza and Melaku, 1996). Seed treatment of maize with carbosulfan showed no effective control of stemborers (Tsedeke and Elias, 1998).

2.5.2 Varietal control

Host plant resistance as a tool of pest control has been successful on the European corn borer *Ostrinia nubilalis* (Hubner) in North America (Harris and Nwanze, 1992).

Some progress has also been reported with *C. partellus* in Africa and Asia (Taneja and Leuschner, 1985). This method of pest control is environmentally safe, economically acceptable by farmers and the most compatible with other components of pest control. The major problem in breeding for resistance to stemborers is lack of efficient screening technique (Harris and Nwanze, 1992).

In Ethiopia, although a considerable number of variety screening activities had been conducted, the output has been discouraging. None of the national collections tested at Awassa were found resistant. At Ambo, however, tolerant maize varieties were reported including PR 85A-2B, PR 85A-251, TL 82A-107, UCA and KCB; and tolerant sorghum varieties were PS No.s 18601-2-2, 18822-4 21113-1, IS No.s 2123 and 3962 (Girma and Fantahun, 1991).

2.5.3 Cultural practices

Cultural practices are an integral part of pest management activities and are most effective when combined with other measures (Edwards and Ford, 1992). Cultural practices reduce survival, germination, development, or spread of pests and include the use of clean, disease-free seed, adjusted planting or harvesting dates, tillage, drainage, crop sequence, crop rotation, plant nutrition (fertilization), and sanitation (Edwards and Ford, 1992).

2.5.3.1 Manipulation of planting time

Reports indicate that the time of planting has a pronounced effect on infestation levels and subsequent yield loss caused by stemborers in maize in several countries, due to the occurrence of distinct periods of moth flight (Van Rensburg *et al.*, 1985; Assefa *et al.*, 1989; Van den Berg *et al.*, 2001). Planting should be carried out at a time when the susceptible stage of the crop coincides with the lowest moth flight (Ebenebe *et al.*, 2000). The precise effects of different sowing dates that result from the interactions of ovipositing females with growing crops vary with locations and seasons. In Ethiopia and Nigeria, early-planted maize is less attacked, while this is not the case in Tanzania and Malawi (Harris and Nwanze, 1992). These differences in infestation due to the interaction of sowing date and location were clearly observed in Ethiopia. Studies at Awasa, southern Ethiopia, have established clear relationships between damage and planting time, where early sowing in mid April had significantly lower infestation of first generation *B. fusca* larvae (Assefa *et al.*, 1989; Assefa, 1990). The number of second-generation larvae was significantly higher on the late sown maize, causing 22.5% to 100% crop loss whereas the early planted crop suffered only 0 to 23.6% crop loss. Planting later than April around Awassa results in great crop yield loss due to the second-generation larvae. High infestation by second-generation larvae appears to be attributed to the high reproductive potential of the moths of the first non-diapause generation (Assefa, 1990). Similarly, at Arsi Negelle, also in southern Ethiopia, stemborer infestations were reported to be lower when maize was planted between 15th and 21st April (Emana, 1998a). At Nazareth area, central Ethiopia, *B. fusca* population and damage increased as planting was delayed but *C. partellus* did not (Melaku, 1999).

2.5.3.2 Crop residue management

The importance of crop residues in carrying over larval populations from one growing season to the next has already been noted (Kfir *et al.*, 2002). An effective control option would be to reduce the first generation of adult population by destroying the larvae in old stalks (Ingram, 1958; Kfir, 1990; Kfir *et al.*, 1989; Unnithan and Seshu Reddy, 1989). Destruction by burning or deep ploughing is feasible although this may not always be possible in some countries where stalks are used for fencing and construction (Harris and Nwanze, 1992). It may then be necessary to devise means of killing diapause larvae without destroying the crop residues. This has been achieved by Adesiyun and Ajayi (1980) by partially burning sorghum stalks, killing 95% of *B. fusca* larvae, while at the same time curing the stalks and making them more suitable for building or use for firewood. Simply leaving stems lying horizontally exposed to full sun in the fields for a month or so, rather than stacking them vertically will reduce the carry-over population, as has been shown in Ethiopia (Assefa, 1988b) and in Nigeria (Harris, 1962). The high level of mortalities in horizontally placed stalks is ascribed to the effects of sun and heat, more specifically, the reaching of the thermal threshold for survival (Pats, 1996).

Farmers are reluctant to accept the idea of spreading stalks on the ground because of termite damage or deterioration of stalks. However, once the duration of effective kill is determined, instead of spreading the stalks in the sun for the entire dry season, doing it for only one month would have acceptance by farmers because the horizontally treated stalks can still be stored in the usual upright position for future use (Assefa, 1988b). Using stalks for fencing, not stacking them upright, reduced stemborer populations significantly (Emana, 2002). However, more cocoon cases were recorded on stalks stacked upright (Emana, 2002).

2.5.3.3 Intercropping and habitat management

The traditional objective of agricultural research has been to enhance crop production in two dimensions: increasing the cultivated area and increasing yields per unit area per crop (Sanchez, 1976). Crop production can still be intensified in two additional dimensions: time and space. The goal of research is to increase food production in both dimensions (Listinger and Moody, 1976). Intercropping is the growing of two or more crops simultaneously on the same field (Andrews and Kassam, 1976). Such cropping systems are widespread on subsistence farms in developing countries of the tropics (Francis *et al.*, 1976). Farmers in Africa adopted intercropping or mixed cropping for centuries in an effort to reduce the risk of crop failure, attain higher yields, and improve soil fertility (Risch *et al.*, 1983; Van den Berg *et al.*, 1998). Although some of these activities may also suppress stemborers, no studies have shown that farmers grow specific intercrops to exploit this effect (Kfir *et al.*, 2002). It is estimated that 98% of cowpea (*Vigna* sp.), probably the most important legume in Africa, is grown in association with other crops (Arnon, 1972). A survey in Northern Nigeria by Norman (1974) reported 83% of the cropland is in mixed cropping. In Colombia 90% of the bean (*Phaseolus* sp.) crop is grown in association with maize (*Zea mays* L.), potatoes (*Solanum tuberosum* L.) and other crops while in Guatemala 73% of the bean production is from associated cropping, principally with maize (Francis *et al.*, 1976).

Farmers insist on preserving traditional systems even when other alternatives, including new varieties best suited for monoculture cropping, become available (Francis *et al.*, 1976). Although their decision-making criteria are poorly understood, diversity of diet and income source, stability of production, reduced insect and disease incidence, efficient use of family labour, and intensive production with limited land resources appear to be important. Crop diversity through mixtures may allow naturally occurring biocontrol agents to sustain higher population levels (Listinger and Moody, 1976). The pest population will respond to the crop species in the mixture as well as to the arrangement of crops in time and space (Listinger and Moody, 1976). Intercropping improves activities of natural enemies of a pest insect. In Kenya, molasses grass was reported to increase parasitism of stemborers by attracting parasitoids (Khan *et al.*, 2001). In Uganda, aphids and leafhoppers were reported to be low on maize intercropped with potatoes (Ebwongu *et al.*, 2001). In Ethiopia, Emana (2002) recently reported lower stemborer population and higher percent parasitism on maize and sorghum plants intercropped with haricot bean (*Phaseolus vulgaris*) but not from the ones intercropped with sesame. Responses to individual intercrops may vary with specific locations, type of intercrops, farming systems, and planting patterns, all of which need to be assessed before practical application.

2.5.4 Biological control

The regulation of pests by natural enemies is one reason many pests seldom reach their full biotic potential. Indigenous parasitic or antagonistic biological control organisms control many soil-born pests of crops (Edwards and Ford, 1992). Some of these biological control agents can be manipulated by specific cultural practices. Such habitat management activities have been generally as effective as the introduction and establishment of exotic biocontrol agents (Edwards and Ford, 1992). It is widely believed that successful biological control is difficult to achieve in annual crops such as maize especially where little permanent or natural vegetation can be found (Edwards and Ford, 1992). However, there are examples of classical biological control that are available or show strong promise for importation and release (with permanent establishment) of predators, parasitoids and pathogens. A related successful approach involves mass rearing and release of the natural enemies when required. Although predators and parasites require specialized release techniques, micro-organisms can usually be applied in a manner similar to that used for chemical pesticides (Edwards and Ford, 1992). Viruses, fungi, and especially the endotoxin of the bacterium *Bacillus thuringiensis* are highly commercialised, whereas most others are still under research and development.

Many pathogens, parasitoids and predators of stemborers have been reported in Africa but there is virtually no rigorous assessment of their importance as factors contributing to pest management (Harris and Nwanze, 1992). Biological control has been effectively used against stemborers on sugarcane in the Caribbean and might be expected to have potential for use against cereal stemborers in Africa (Harris and Nwanze, 1992). Over the past 60 years, there have been numerous attempts to introduce exotic parasioids into Africa and the Indian Ocean Islands for biological control of exotic and native stemborers, but only a few species have established (Table 1.2) (Kfir *et al.*, 2002).

There are a large number of hymenopterous parasitoids of cereal stemborers in Asia and one, the gregarious larval endoparasitoid, *Cotesia flavipes* Cameron, has already been introduced from Pakistan into eastern and southern Africa (Overholt *et al.*, 1994a, 1997). On the mainland, only *C. flavipes* is established, which also failed to be recovered in South Africa after the winter season, unlike in eastern Africa. Kfir *et al.* (2002) reviewed the chronological history, success and failure of *C. flavipes* introduction and establishment into Africa (Table 2.2).

Mohyuddin and Greathead (1970) suggested the importance of distributing the stemborer biocontrol agents, namely *Inveria soudanensis* (Steffan) and *Sturmiopsis parasitica* (Curran) within Africa, as geographic barriers seemed to restrict the range of these two species. Ingram (1983) emphasised the need for further critical ecological analysis to pinpoint areas where release of further parasitoid species are most likely to be effective. Little is known about predation on stemborers, other than occasional references to ants attacking eggs and first instar larvae.

Table 2.2 Exotic stemborer parasitoids established in mainland Africa and Indian Ocean Islands.

Country	Year of release	Host stage attacked	Parasiotid species	Target host attacked	Crop	Origin
			Mainland			
Kenya	1993-1997	Larva	*Cotesia flavipes*	*Chilo partellus*	Maize	Pakistan/ India
Mozambique	1996-1999	Larva	*Cotesia flavipes*	*Chilo partellus*	Maize	Pakistan/ India
Uganda	1997-1999	Larva	*Cotesia flavipes*	*Chilo partellus*	Maize	Pakistan/ India
Tanzania	Not release	Larva	*Cotesia flavipes*	*Chilo partellus*	Maize	?
Ethiopia	No release	Larva	*Cotesia flavipes*	*Chilo partellus*	Maize	?
			Islands			
Mauritius	Unknown	Larva	*Cotesia flavipes*	*Chilo sacchariphagus*	Sugarcane	Unknown
	1951-1952	Larva	*Cotesia sesamiae*	*Sesamia calamistis*	Maize, sugarcane	Kenya
	1939	Larva	*Bracon chinensis*	*Chilo sacchariphagus*	Sugarcane	Sri Lanka
	1939	Pupa	*Xanthopimpla stemmator*	*Chilo sacchariphagus*	Sugarcane, maize	Sri Lanka
	1963	Pupa	*Trichospilus diatrraeae*	*Chilo sacchariphagus*	Sugarcane	India
Reunion	Unknown	Larva	*Cotesia flavipes*	*Chilo sacchariphagus*	Sugarcane	Unknown
	1953-1955	Larva	*Cotesia sesamiae*	*Sesamia calamistis*	Maize, sugar	Mauritius
	1953, 1960	Pupa	*Xanthopimpla stemmator*	*Chilo sacchariphagus*	Sugarcane	Mauritius
				Sesamia calamistis	Maize, sugarcane	Mauritius
Comoros	1969-1971	Pupa	*Pediobius furvus*	*Sesamia calamistis*	Maize	Madagascar
Madagascar	1961	Larva	*Cotesia flavipes*	*Chilo sacchariphagus*	Sugarcane	Mauritius
	?	Larva	*Cotesia sesamiae*	*Sesamia calamistis*	Maize, sugarcane	Uganda
	1968	Pupa	*Pediobius furvus*	*Sesamia calamistis, Sciomesa biluma*	Maize	Uganda

Source: Kfir *et al.* (2002).

Assefa (1983, 1985) reported seven natural enemies of *B. fusca*, four larval and two pupal parasitoids in Ethiopia. He further stated that *C. sesamiae* was the most widespread larval parasitoid, which caused 25.4% parasitism. Other minor parasitoids included *Eupelmus* spp., *Procerochasmias nigromacullaus* (attacking pupa) and *Telenomus busseolus*. Kassahun (1996) reported 71% parasitism of *B. fusca* larvae by *Dolichogenidea fussivora* during the dry season in eastern Ethiopia. The bacterial preparation *Bucillus thuringiensis* (Bt) tested against *B. fusca* gave comparable results to DDT (IAR, 1983). However, Adhanom and Abraham (1986) reported poor performance of Bt against *B. fusca*. At Ambo, *Bitoxi bacillin* and *Dendrobacillin* caused 80-90% larval mortality (Girma and Fantahun, 1991).

Recently, Emana (2002) recorded 20 parasitoids from orders Hymenoptera and Diptera in Ethiopia. He also reported that *Cotesia flavipes* was the most abundant and widely distributed parasitoid that attacked all stages of *C. partellus*, the level of parasitism ranging between 0.01 to 7.47%, but was also found on *B. fusca* and *S. calamistis*. Fourteen predators from orders Dermaptera, Hymenoptera, Coleoptera and Heteroptera, three entomopathogenic fungi and four nematodes were also recorded (Emana, 2002)

CHAPTER THREE

GENERAL MATERIALS AND METHODS AND ECOLOGICAL DESCRIPTION OF THE STUDY AREA (THE AMHARA STATE)

3.1 The study area

The study was conducted for two years, i.e., from May 2003 to January 2005, in the Amhara National Regional State (ANRS), herewith referred to as the Amhara State, or State, which is located in Northwestern part of Ethiopia, and it is one of the Regional States in the Federal Democratic Republic of Ethiopia. It is situated between $8^0 45'$ N to $13^0 45'$ N latitude and $35^0 46'$ E to $40^0 25'$ E longitude and has an area of 170, 000 km^2 (PEDB, 1999). Rainfall in the State gradually increases from 300 mm in eastern Amhara to over 2000 mm in western Amhara. Much of the western part of the State receives more than 1200 mm rainfall as it is situated in the windward side of the rain-carrying summer monsoon. The summer monsoon is the only effective rainy season that lasts up to six months in some far western districts of Amhara state. The eastern part, however, has bimodal rainfall distribution as it has an additional small rainy season in spring due to easterly winds, but the region as a whole is semi-arid.

In area coverage, the State stands third, next to Oromiya and Somali states, covering 15% of the country's land area, and is bordered by four regional states viz., Tigray, Afar, Oromiya, Benishangul-Gumz in the North, South, and Southwest, respectively, and by Sudan in the North-west.

The State is divided into eleven zones including the capital city, Bahir Dar, which has been designated as a special zone. The ten remaining zones are North Gondar, South Gondar, East Gojam, West Gojam, Awi, North Wolo, South Wolo, North Shoa, Oromiya and Wag Himera. There are 105 districts including six zonal centers with a district status. Wag Himera is a remote zone and was not included in the study. The Amhara state is shown in Fig. 3.1.

3.1.1 Physical characteristics of the Amhara state

3.1.1.1 Agro-ecological zones

The Amhara State has a wide range of agricultural environments. This is depicted by the great geographical diversity with high and rugged mountains, extensive flat-topped plateaus and deep gorges, incised river valleys and rolling plains (BOA ANRS, 1999; Alemayehu, 2003). The effects of altitude on temperature and evapo-transpiration and therefore on soil texture are always compounded with those of relief. This is particularly true in the northern and eastern highlands of the state where sharp changes in climate and soils occur. The highlands of Wolo are very heterogeneous with a variety of landforms, diversified due to differences in elevation, geology, edaphic conditions, steepness and orientation in slope, wind and precipitation. These factors contribute to variations within short distance. According to the recent agro-ecological classification by the Natural Resources Management and Regulatory Department of the Ethiopian Ministry of Agriculture in 1998, the Amhara state is divided into 10 major agro-ecological zones. The zones are further divided into 18 sub-agro-ecological zones using the different physiographic units including lowland plains, lakes and rift valleys, valleys and escarpment, gorges, mountains and plateaus.

Although there are areas with different agroecological and socio-economic characteristics classified as a single zone (e.g. M2-5), most of the sub-agro-ecologies seem to be more homogenous in terms of moisture availability period, thermal conditions and physiographic characteristics.

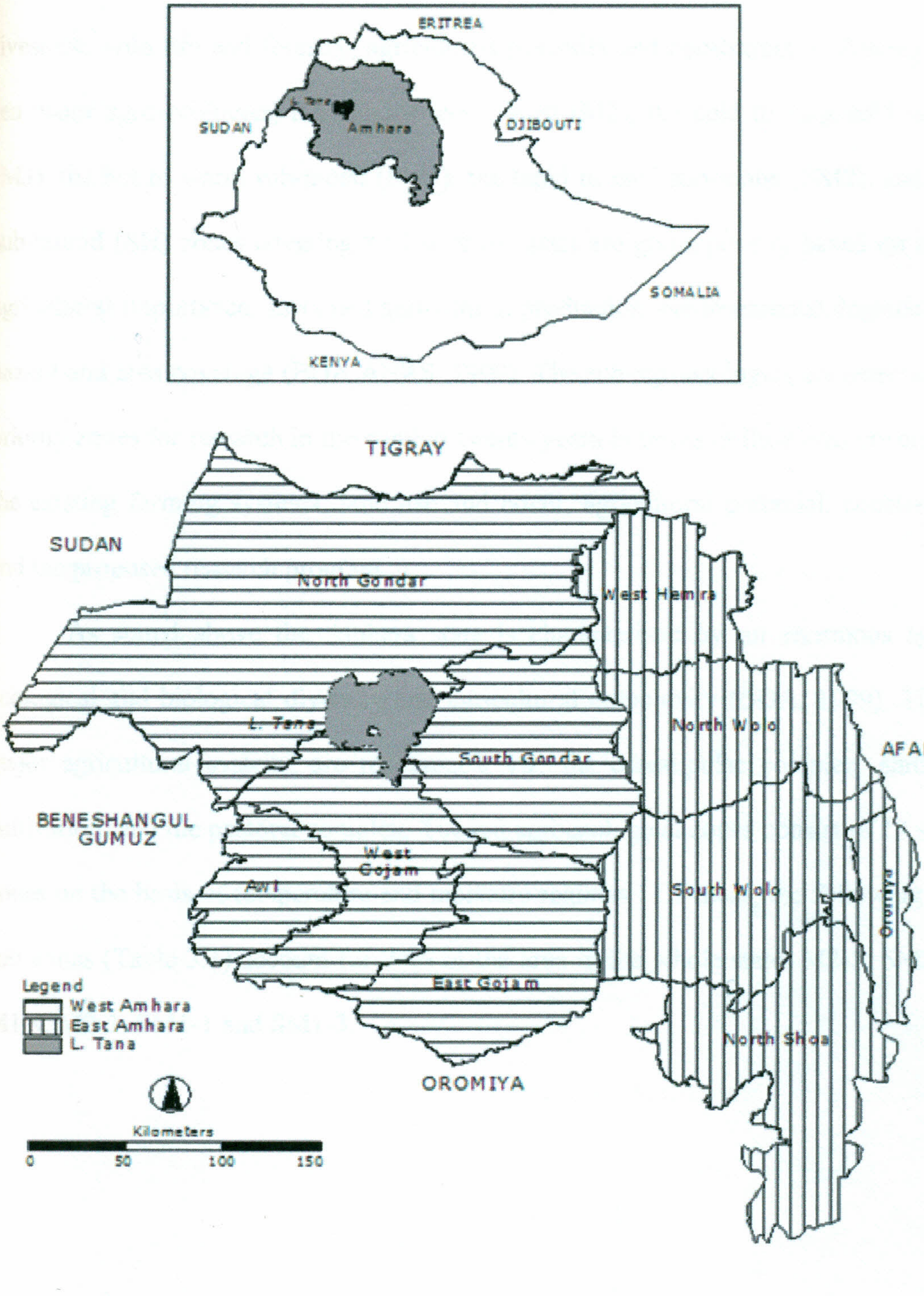


Fig. 3.1 The semi-arid eastern and the cool-wet western regions and the respective zones of the Amhara State in Ethiopia (each region has five zones).

The sub-agro-ecologies are characterized by parameters of climate, soils, elevation, land use and vegetation cover, physiography, farming systems, available crops, livestock, wild life and forestry, agricultural potential and constraints. Among the ten major agro-ecologies, the tepid to cool moist (M2), the cold to very cold moist (M3), the hot to warm sub-moist (SM1), the tepid to cool sub-moist (SM2), and the sub-humid (SH) zones covering 84.2% of the state are given priority based on their agricultural importance, sustained agricultural production, environmental degradation hazard and area coverage (BOA ANRS, 1999). The sub-agroecologies are selected as priority zones for research in the coming twenty years in terms of their area coverage, the existing farming systems, land use and cover, agricultural potential, constraints and the proposed research program.

As stated above the Amhara state is characterized by an enormous agro-ecological and biological diversity and agricultural complexity (BOA, 1999). Three major agricultural systems are recognized, viz. the cereal/pulse complex, shifting cultivation, and the pastoral complex. The ten agroecological zones consist of 18 sub-zones on the basis of temperature and moisture regimes. Of these, the following six sub-zones (Table 3.1) account for 74% of the area in the whole state: M2-5, SM2-5, M1-4, M2-1, SM1-1 and SM1-3.

Table 3.1 Major agro-ecological sub-zones of the Amhara State

Rank	Sub-zone	Percent of total area	Description
1	M2-5	33.2	Moist, tepid to cool plateau and mountain
2	SM2-5	22.1	Tepid to cool sub-moist plateau
3	M1-4	7.3	Hot to warm moist lowland
4	M2-1	4.5	Tepid to cool moist plains
5	SM1-1	6.3	Hot to warm sub-moist plateau remnant
6	SM1-3	0.4	Hot to warm sub-moist lowlands

3.1.1.2 Soils

The nature and type of soils differ from place to place and from time to time. This is due to such factors as climate, parent material, vegetation, and man (FAO, 1984; PEDB, 1999; Alemayehu, 2003). The parent material has an important role in determining the nature of soils and other biotic factors, through determining the soil's fertility, productivity, etc. The parent materials for most parts of the State's soils are volcanic rocks and some parts have sandstone, limestone, etc., (FAO, 1984; PEDB, 1999; Alemayehu, 2003). The following 12 types of soils are identified in the state: Arthic Acrisols, Cambisols, Rendzina, Phaezoms, Lithosols, Fluvisols, Luvisols, Nitosols, Arenosols, Regosols, Andosols, and Vertisols. The present surveys and field experiments were carried out in some of these soil types.

3.1.1.3 Rainfall

The mean annual rainfall in the state varies between 300 mm in Eastern Amhara covering North Wolo (Habru and Kobo districts), to over 2000 mm in the west where parts of Gojam (Banja, Sekela and Gwangua districts), and a small area in North Shoa (Mezezo and Basona Worana districts) (PEDB, 1999; Alemayehu, 2003). Most of the western part and the highest spots of the state enjoy annual rainfall in excess of 1200 mm. This is due to the fact that these areas are situated on the windward side of the rain bringing summer monsoon, which reaches the area from south-westerly to westerly directions. The low rainfall areas in the state are most parts of northern Wolo and Wag Himera zones and this can be explained by the fact that these areas are in the rain shadow of the escarpment and the Siemen Mountains, respectively.

The western part of the Amhara State, specifically all parts of Gojam, Gondar, northwestern part of Wolo (Bugna, Gidan and parts of Meket districts) and Wag Himera (Dahina district) receive rains in summer where the summer monsoon is the only significant source of rainfall (PEDB, 1999). The rest of Wolo, North and South Wag Himera, Oromiya and North Shoa zones receive small rains in spring, big rains in summer merging together. Here too, much of the rain falls during the monsoon period, but moist easterly to south easterly winds during spring and to a lesser extent, during autumn bring additional, substantial amounts of precipitation (PEDB, 1999).

3.1.1.4 Natural regions

Vegetation, rainfall, soil fertility and length of growing period are used to classify natural regions of an area. So far, four major natural regions are identified in the Amhara State, including afroalpine and subafroalpine, coniferous forest, broad-leaved forest and woodland savannah region (PEDB, 1999; Alemayehu, 2003).

3.1.1.5 Length of growing period

The length of growing period is the number of days in a year in which the available water in the soil allows crops to grow (PEDB, 1999). The amount and distribution of rainfall and potential evapo-transpiration determine the length of growing period of crops. These climatic parameters (i.e., rainfall and potential evapo-transpiration) indicate whether there is surplus or deficit in soil moisture. The length of a growing period of crops has a close relationship with rainfall and temperature distribution. In an area where there is high rainfall and low temperature, the length of a growing period is longer and such conditions prevail in mountains and highland areas and the reverse is the case for low rainfall and high temperature areas. Apparently, the latter is the characteristic of lowlands.

A larger portion of the state stretching west of the eastern escarpment enjoys one normal and dependable annual growing period during the summer monsoon. In this part of the state, the length of the growing period varies from less than 120 days in Wag Himera to more than 270 days in West Gojam (Banja, Sekela) and in Awi (Gwangua districts). The length of the growing period in eastern and southern parts of the state have varies from 45 to 90 days and 60 to 210 days, respectively. A strip of land east of the escarpment enjoys an intermediate type of growing period one in spring and the other in summer/autumn. Close to Debre Sina and Ankober (North Shoa), the spring growing period merges with the summer/autumn period to form all year round growing period of 365 days. Also in South Wolo around Mersa, the spring and summer growing periods overlap to produce a total length of a growing period of more than 240 days (PEDB, 1999).

3.1.2 Crop production and its constraints

As elsewhere in the country, agriculture plays a key role in the state's economy and the livelihood of its people (BOA, 1999). The major crops produced include cereals, legumes, oilseed crops, vegetables, and fruit crops (CACC, 2003). Cereal crops occupy 73% of the annually cropped land with food legumes and oil seeds following in that order. The main cereal crops grown are *tef,* barley, wheat, sorghum, maize, and finger millet. Faba bean, field pea, lentils, and chickpea among the food legumes and niger seed among the oilseeds also cover appreciable land area. Peasant farmers produce about 90% of the food grains in the state, employing largely techniques. Land holdings greatly vary ranging between 0.5 and 3 hectares or less, depending on the geographical area. Land preparation is done by oxen drawn local plough, the *maresha*; weeding is dependent up on labour intensive practices; irrigation practices, improved seeds and other external inputs such as pesticides is minimal (BOA, 1999).

The most important features of the agricultural systems in the state are their complexity and diversity. Crop rotation is a common practice of agricultural production. It is not uncommon to see patches of different crops (cereals and legumes, cereals and oilseeds, cereals and cereals, cereals and trees) growing side by side in the predominantly cereal-based farming systems of the highlands in the sate.

The state with a population of over 17 million covers an area of 170 thousand km^2. The huge ago-ecological diversity ranges from desert (< 500 m a.s.l.) to alpine (> 3000 m a.s.l.) (Table 3.2). Thus, there is a vast plant and animal variety. Such agro-ecological heterogeneity entails a vast hidden and unexploited potential that could be tapped to raise a wide range of crops and animals to provide adequate food and balanced nutrition for its increasing human population (estimated per annum at 2.6% for rural and 4.9% for urban areas). On the other hand, it is a cause for myriads of problems especially those problems associated with crop losses (pests, diseases, parasitic weeds, drought, etc.). Furthermore, technologies developed for a specific agro-ecological zone may not be applicable by the other. Despite the huge volume of grain production in the Amhara state, which places it second in Ethiopia in both maize and sorghum production, only after Oromia (Table 3.3), and first in legume and oilseed crop production, the state still faces chronic food and cash crop shortage. This situation made it unable to feed its ever increasing human population, obtain sufficient foreign exchange to purchase agricultural and industrial inputs to enhance production and to produce enough to feed local processing agro-industries and absorb the young and the unemployed (BOA, 1999). Crop yields have remained low (Table 3.4); although research results from research centers and on-farm trials indicate that there is a tremendous potential to increase productivity.

Table 3.2 Traditional Amhara climatic zonation

Climatic zone	Local name	Altitude	% Area coverage	Hectares
Desert	Bereha	< 500	3.1	527,000
Lowland	Kola	500-1500	28.0	4,760,000
Mid-altitude	Woina Dega	1500-2300	44.3	7,531,000
Highland	Dega	2300-3200	20.5	3,485,000
Alpine	Wurch	>3200	3.9	663,000

Source: BOA, 1999

Table 3.3 The status of maize, sorghum and other crops produced in different states of Ethiopia in 2001/2002 cropping season.

a) Maize

State	Number of farm families	Area (ha)	Production (tons)	Yield (t/ha)
Tigray	382,838	52,217.67	89,497.20	1.71
Afar	8,252	6,100.41	6,051.56	0.99
Amhara	1,712,860	296,356.11	637,489.58	2.15
Oromia	2,578,627	729,461.83	1,660,387.42	2.27
Somali	64,766	20,846.55	26,344.73	1.26
Benishangul-Gumuz	93,617	20,482.45	412,52.56	2.01
S.N.N.P.R.	907,707	191,490.02	327,037.72	1.71
Gambela	21,336	5,110.06	10,986.75	2.15
Harari	8,726	667.56	826.74	1.24
Addis Ababa	2,316	47.39	4.62	0.10
Dire Dawa	4,690	257.46	329.98	1.28
Ethiopia (Total)	5,785,735	1,323,037.53	2,800,208.87	2.12

b) Sorghum

State	Number of farm families	Area (ha)	Production (tons)	Yield (t/ha)
Tigray	267,570	114,058.73	192,349.23	1.7
Afar	2,304	1,404.78	1,094.06	0.8
Amhara	954,611	409,473.20	522,628.51	1.3
Oromia	1,477,381	437,397.55	635,585.29	1.5
Somali	51,192	20,824.36	27,905.43	1.3
Benishangul-Gumuz	91,011	52,375.42	67,039.07	1.3
S.N.N.P.R	530,724	84,276.06	84,200.95	1.0
Gambela	9,906	2,664.26	3,321.79	1.2
Harari	12,374	3,834.52	3,489.21	0.9
Addis Ababa	140	26.51	19.59	0.7
.Dire Dawa	13,750	6,160.24	8,574.94	1.4
Ethiopia (Total)	3,410,963	1,132,495.63	1,546,208.08	1.4

c) Production of maize and sorghum and other crops in the Amhara State in 2001/02

	Crop type	Area (ha)	Production (tons)
		Grain crops	
		3,061,006.65	3,376,205.09
Cereals		2,350,341.66	2,781,431.11
	Tef	796,635.09	709,362.04
	Barley	347,672.52	336,065.86
	Wheat	300,791.36	364,110.18
	Maize	313,548.09	652,710.89
	Sorghum	415,223.50	525,965.87
	Finger millet	156,462.06	168,293.18
	Oats	13,354.82	11,682.33
	Rice	6,654.21	13,240.76
Pulses		531,665.80	507,558.21
	Horse beans	170,124.14	21,164.71
	Field peas	87,192.41	68,549.75
	Haricot beans	29,983.88	17,847.93
	Chickpea	118,448.93	108,978.70
	Lentils	54,046.57	28,858.85
	Grass pea	55,551.86	60,038.04
	Soya beans	256.75	206.83
	Fenugreek	8,833.14	5,976.35
	Lupine	7,228.13	5,937.05
Oilseeds		178,999.20	87,215.78
	Niger seed	120,023.38	45,130.77
	Linseed	24,240.60	10,679.44
	Safflower	4,260.21	3,785.96
	Sesame	19,963.21	23,672.76
	Mustard	8,813.00	12,262.07

	Vegetables	
Head cabbage	116.96	917.31
Ethiopian cabbage	861.12	3,489.33
Tomatoes	468.61	*
Green peppers	853.82	7,948.35
Red peppers	16,557.79	19,596.91
Swiss chard	27.19	258.25
	Root crops	
	79,111.93	499,921.63
Beetroot	90.97	746.85
Carrot	199.58	1,414.03
Onion	4,788.48	122,951.19
Potatoes	71,325.18	339,353.37
Garlic	2,483.83	33,730.26
Sweet potatoes	207.06	1,725.82
All	3,159,027.70	3,919,779.83

Source: CACC, 2003.

Table 3.4 Average crop yields in the Amhara state: some examples

Crops	Yield (t/ha)	Potential (on-station) yield (t/ha)
Tef	0.8	2.0-2.5
Wheat	1.0	3.0-4.0
Barley	1.0	3.0-4.0
Maize	1.7	5.0-6.0
Sorghum	1.3	4.0-5.0
Faba bean	0.9	3.0-3.5
Field pea	0.6	2.5-3.0
Haricot bean	0.7	2.5-3.0
Chickpea	0.8	2.5-3.0
Niger seed	0.4	1.5-2.0
Rapeseed (mustard)	1.2	1.5-2.0
Fenugreek	0.7	1.5-2.0

Source: BOA, 1999

It has often been stated that pests (insects, weeds, diseases, rodents, etc.) at the pre and post harvest stages account for 30-40% crop losses in Ethiopia. The position of the Amhara state will not be far from this national figure (BOA, 1999). However, no comprehensive critical assessment has been made on crop losses in the state and therefore it is not possible to verify the figures (BOA, 1999). Furthermore, opportunity losses due to lack of proper implements, farm transport, storage facilities, and wastage due to traditional food processing and preservation methods have hardly been accounted for. Lack of accurate figures on pre and post harvest losses makes it difficult for policy makers to have a workable agricultural planning. Little is known of the geographic distribution, species composition, and management techniques of crop pests (certainly including stemborers) in the Amhara state (BOA, 1999) (Table 3.5). The gap in knowledge of parasitoids and predators is far more than their hosts.

Table 3.5 Examples of major diseases and pests on selected crops in the Amhara state.

Crop	Diseases	Insect	Weed
Tef	Rust	Bush crickets	Grasses
		Grasshoppers	
Maize	Leaf blight	Stalk borers	Striga
	Streak virus	Weevils	
	Rust	Army worm	
		Cutworm	
Sorghum	Smuts	Stalk borers	Striga
	Grain mould	Weevils	
	Anthracnose		
Wheat	Rusts	Aphids	Complex
	Septoria		
	BYDV		
Barley	Rusts	Barley fly	Complex
	Scald	Aphids	
	BYDV		
Faba beans	Chocolate spot	African bollworm	Orobanche
	Rust	Aphids	Complex
Field peas	Ascochyta leaf spot	African bollworm	Common weeds
	Powdery mildew	Pea aphids	
Chickpeas/lentils	Wilts	African bollworm	Common weeds
	Root rots	Pea aphids	
Potatoes	Late blight	Tuber moth	Complex
	Viruses		
Tomatoes	Late blight	Fruit worm	Common weeds
	Early blight		
Pepper	Viruses	Bleaching	Common weeds
	Powdery mildew	African bollworm	
Onion	Purple blotch	Thrips	
Citrus	Viruses	Scales	
	Foot rot	Fruit worm	

Source: BOA, 1999. BYDV stands for Barley yellow dwarf virus; faba beans are also called horse beans.

3.2 Surveys

In 2003 surveys were conducted only during the main season (from June to December). In 2004, in addition to the main season, we conducted one survey during the small rains (in May), especially in eastern Amhara, a semi-arid region with predominantly bimodal rainfall distribution.

The target area for the survey, i.e., the Amhara State, was systematically categorized into two major agro-ecologically distinct regions, semi-arid eastern and the wet western Amhara. Eastern Amhara included North Shoa, Oromiya, South and North Wolo administrative zones. Western Amhara included North and South Gondar, West and East Gojam, and Awi administrative zones. In each of the zones where cereal production is practiced, a variable number of districts, and several localities within each district, were surveyed.

3.3 Field and laboratory studies

Field trials were conducted in 2003 and 2004 in western and eastern Amhara. In western Amhara, trials were carried out at three agro-ecologically distinct locations: i.e., at Addis Zemen (1830 m elevation, 12 degrees 04 minutes 07 seconds N, 37 degrees 43 minutes 41 seconds E), Nitosols, gentle slope to plain landscape, where sorghum and tef are the major crops, and the soil is well drained; and Kola Diba area (1842 m elevation, 12 degrees 25 minutes 04 seconds N, 37 degrees 19 minutes E), heavily waterlogged Vertisol plain,) and also on well-drained red soil. The third site was Zema (1828 m elevation, 11 degrees 9 minutes N, 37 degrees 43 minutes E), and vertic soil type, the gentle slope helped drain excess water during the peak rainy season; lowland vegetation, *Euphorbia*, dominate the area. *B. fusca* is the major stemborer species in these three sites.

In eastern Amhara, the same set of experiments was conducted at Chefa Experimental Field (1479 m elevation, 10 degrees 51 minutes 20 seconds N, 39 degrees 48 minutes 56 seconds E, vertic soil type, loam soil texture, waterlogged plain, where sorghum, *C. partellus* and *C. flavipes* dominated area). Fig. 3.2 shows the trial sites.

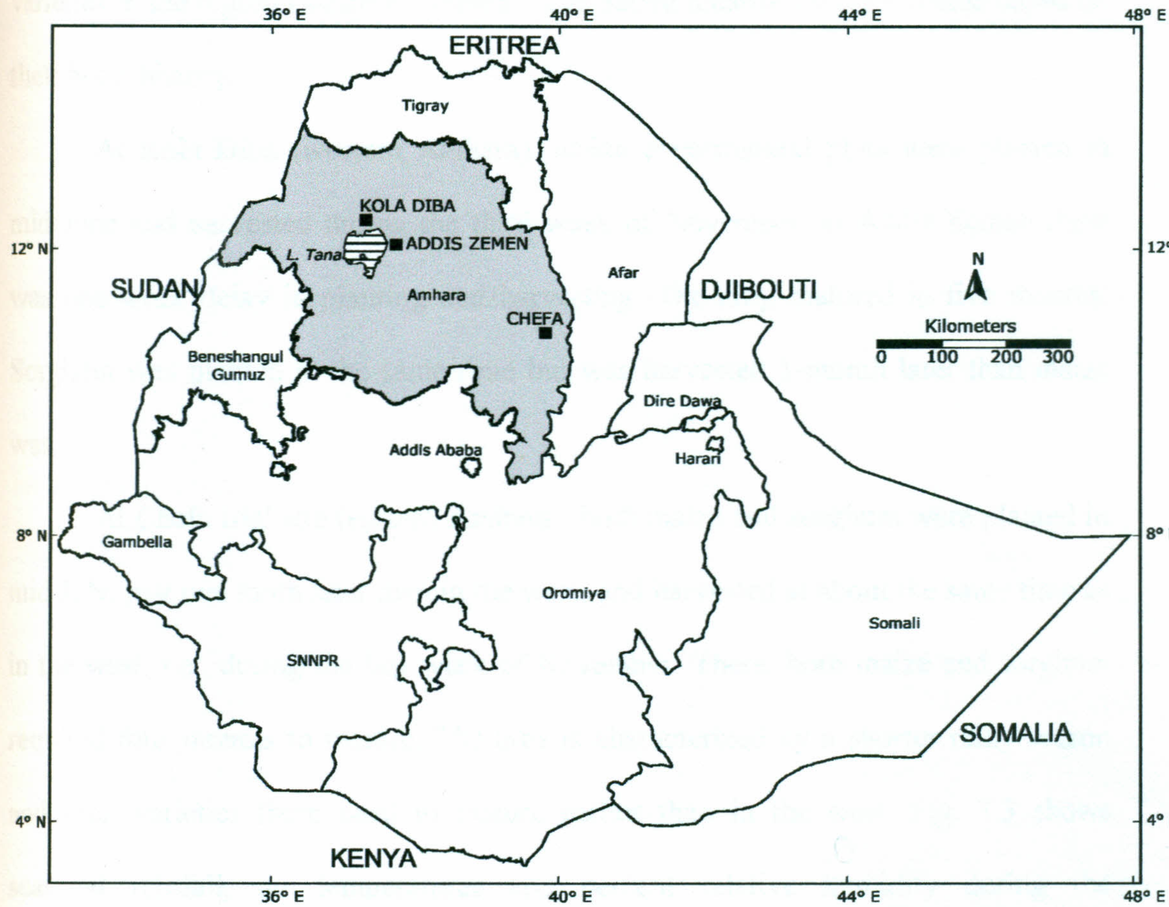


Fig. 3.2 Trial sites (Kola Diba, Addis Zemen and Chefa) in the Amhara State.

Field trials included, a) yield loss assessment due to stemborers at various nitrogen fertilizer levels by exclusion methods (insecticide application), b) effect of cropping system by using indigenous intercrops (varies with farming systems of each region), and c) planting time on stemborers and their natural enemies (in western Amhara). The maize variety used, *BH 540*, is the finest and earliest maturing of released varieties in the region (western Amhara). The above locations were selected based on their borer history.

At Kola Diba (western Amhara), maize experimental plots were planted in mid June and harvested during the third week of November; at Addis Zemen there was one week delay in planting and harvesting. The crop matured in five months. Sorghum was planted at the same time but was harvested 1-month later than maize was.

At Chefa trial site (eastern Amhara), both maize and sorghum were planted in mid July, just one moth later than in the west, and harvested at about the same time as in the west, i.e., during the last week of November. There, both maize and sorghum required four months to mature. The area is characterized by a shorter rainy season and crop varieties there need to mature earlier than in the west. Fig. 3.3 shows seasonal rainfall, air temperatures and percent relative humidity during the experimentation period. At Chefa trial site, the graph shows the main season weather variables when the trial was done, although, normally there are two seasons, small rains from January to May (effective from March to April), and main rains from June to September.

Plots were 6 m long × 8 rows × 0.75 m row spacing. Spacing between replicates, plots and plants were 3 m and 2 m, and 0.30 m, respectively. Two maize seeds were planted per hill at a spacing of 0.30 m between plants.

Assessment

At all sites, the following data were recorded. Egg density was assessed on a random sample of 10 plants per plot at 3 weeks after crop emergence (data not presented because egg population was low). Non-destructive and destructive sampling was carried out at the vegetative, reproductive and harvest stages. For destructive sampling, 10 plants per plot were randomly selected and cut at ground level from the four outermost rows per plot, two rows on each side of the plot. These plants were then dissected to find all stages of borers, which were counted, identified and then taken to the laboratory and reared for the emergence of adults or natural enemies. Plant height, basal diameter, number of internodes, leaves and holes per plant and stem tunnelling were recorded.

Statistical analysis

Differences in mean borer population, damage, percent parasitism and grain yield were analysed using the procedure of the General Linear Model of SAS (SAS, 1999-2000), followed by mean separation using SNK when the main effect contributed significantly ($P<0.05$) to the model variance. Correlation, stepwise and logistic regression analysis were conducted.

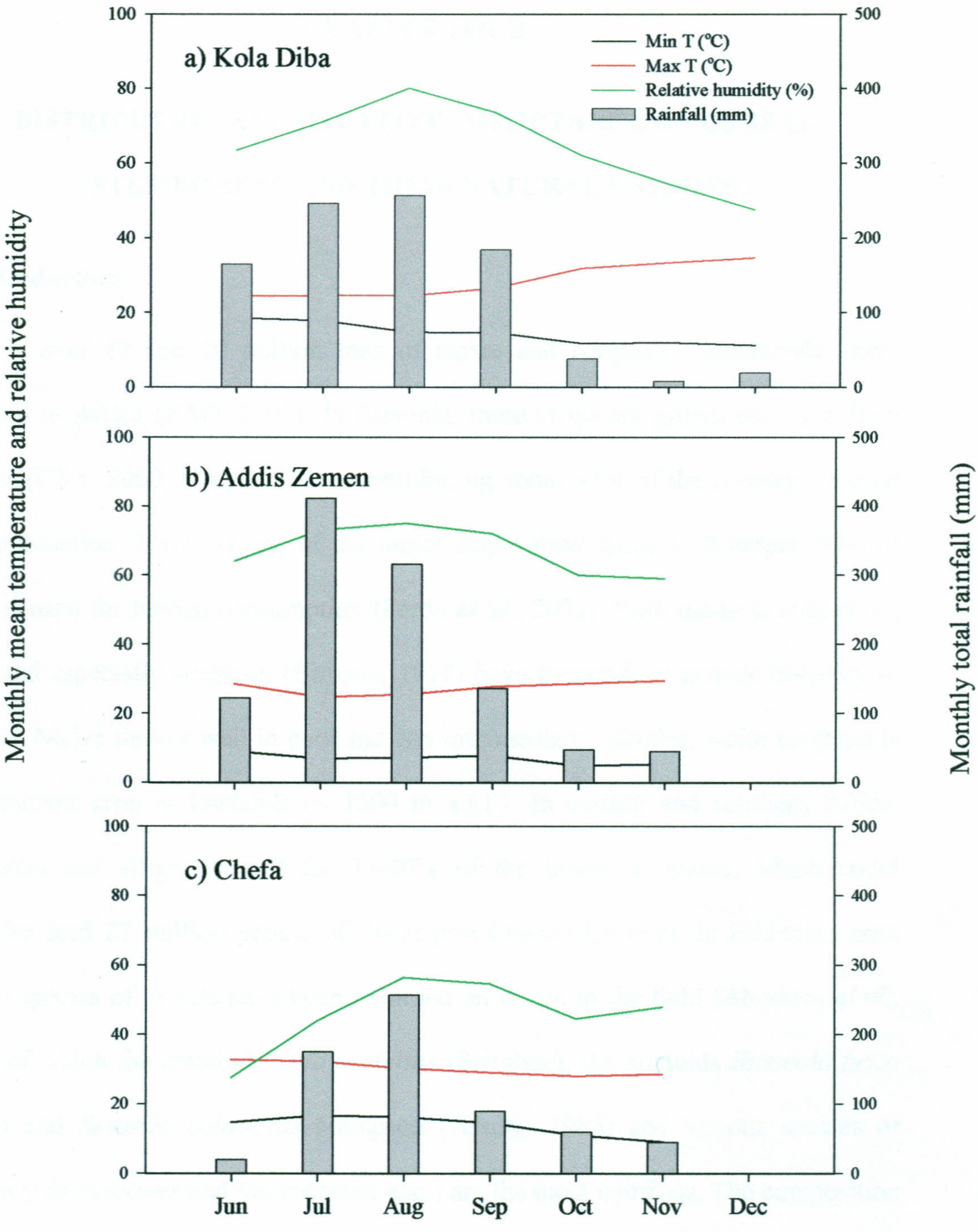


Fig. 3.3 Some climatic variables in the trial sites in 2004 experimentation period.

CHAPTER FOUR

DISTRIBUTION AND RELATIVE IMPORTANCE OF CEREAL STEMBORERS AND THEIR NATURAL ENEMIES

4.1 Introduction

In 2002, over 42 and 20 million tons of maize and sorghum, respectively, were produced in Africa (FAO, 2003). In Ethiopia, these crops are grown on 2.4 million hectares (CSA, 2000; CACC, 2003), contributing about 41% of the country's annual grain production. Maize is one of the major staple food crops in Ethiopia, 90% of which is used for human consumption (Ferdu *et al.*, 2001). Both maize (Ferdu *et al.*, 2001) and especially sorghum (Birhane, 1977) have tremendous genetic diversity in Ethiopia. Maize thrives well in cool and wet intermediate altitudes, while sorghum is the dominant crop in lowlands (< 1500 m a.s.l.). In eastern and southern Africa, stemborers and striga account for 15-40% of the losses in maize, which could otherwise feed 27 million people of the region (www.icipe.org). In Ethiopia, more than 40 species of insects have been recorded on maize in the field (Abraham *et al.*, 1993), of which the crambid *Chilo partellus* (Swinhoe), the noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson (Assefa, 1985) and various species of termites (*Macrotermes* and *Microtermes* spp.) are the most injurious. The composition is more or less the same on sorghum. Recently, *Sesamia nonagrioides botanephaga* Lefebvre (Lepidoptera: Noctuidae), *Rhynchaenus niger* (Horn) (Coleoptera: Rhynchophoridae), *Pissodes dubius* (Strom) (Coleoptera: Rhynchophoridae), and the exotic stemborer parasitoid *C. flavipes* were reported in eastern Amhara and some other parts of Ethiopia (Emana, 2002; Emana *et al.*, 2003; Melaku Wale, unpub.). *C. flavipes* was introduced in 1993 into Kenya (Overholt *et al.*, 1994a) by the

International Centre of Insect Physiology and Ecology (ICIPE), Kenya, as part of a classical biological control program now encompassing eleven countries in eastern and southern Africa. Ever since its introduction, it has reduced stemborers by 60% and increased yields by 10-15% in coastal Kenya (Overholt *et al.*, 1997; Zhou *et al.*, 2001). It is believed to have invaded Ethiopia probably from Somalia where it was introduced in 1997 (C. Omwega, ICIPE, Kenya, pers. comm.).

Reported crop losses in Ethiopia by the major stemborer species, *C. partellus* and *B. fusca*, range from 15 to 100% (Assefa, 1989; Tadesse, 1989; Gashawbeza and Melaku, 1996; Emana, 1998b). Information about the species composition and pest status of stemborers and their natural enemies in the Amhara State is scanty. There is no literature specific to the region that could be cited. Observations and general surveys in the region showed that borers are aggravating recurrent famines especially in eastern Amhara (Melaku Wale, unpub.; BOA, 1999; Shegaw *et al.*, 1999; Emana, 2002). Information about the relative importance of a key pest is a prerequisite for priority setting in pest management (Ndemah *et al.*, 2001a) and filling the gap would contribute to food self-sufficiency in the State. Thus, the objectives of the current study were to determine the relative importance of different stemborer species and to establish a catalogue of natural enemies in the Amhara State.

4.2 Materials and methods

4.2.1 Survey area

Survey areas were the eight maize and sorghum growing administrative zones of the Amhara state (Fig. 4.1.). The Amhara state is divided into semi-arid eastern and cool-humid western Amhara (Fig. 4.1). A total of 156 localities were surveyed from 2003 to 2005 (Fig. 4.1). The number of localities or fields, which were selected randomly from each district, varied between zones depending on the scale of cereal production in each zone. The latitude, longitude, and elevation of the study sites were determined with Global Positioning system. Altitudes of the target area ranged from 1200 to 1985 m a.s.l. for eastern Amhara, and 1300 to 2600 m a.s.l. for western Amhara.

4.2.2 Sampling procedures

For determination of infestation levels and borer species, fields were sampled at seedling, knee height, flag leaf, tasseling, grain filling, and maturity stages. The study was mostly conducted during the main growing season (June to December each year). The specific dates of surveys varied because of differences in agro-ecologies and the farming systems between the two regions. Much of eastern Amhara grows sorghum. Late maturing varieties (8-9-month variety), which grow as tall as 4m, are planted in April (short rains), other varieties are planted between May and June (6-7 month variety) the third group of varieties (5-month varieties) are planted in July (main rainy season) and all the three groups are harvested more or less at the same time, i.e., in December. Except for one trip in May 2004, the short rainy season was not covered in the study. The short rainy season is not sufficient to grow crops in western Amhara. Both destructive and non-destructive sampling methods of host plants were done. Each field was divided into 4 sections from which 3×3 m^2 plots were sampled. Plant density, number of infested plants, dead-hearts, leaf damage, and other agronomic data were recorded on the plants within the 1-m^2 quadrants. Furthermore, 5-20 plants were randomly selected per section and dissected for determination of larvae and pupae as well as of natural enemies. Plant growth stage, plant height, stem diameter, number of internodes (damaged and undamaged), length of stem tunnelling, number of holes, number of borers, cocoon masses, and other natural enemies (parasitoids and predators) were recorded. Common predatory earwigs and ants were sometimes observed preying on borer larvae.

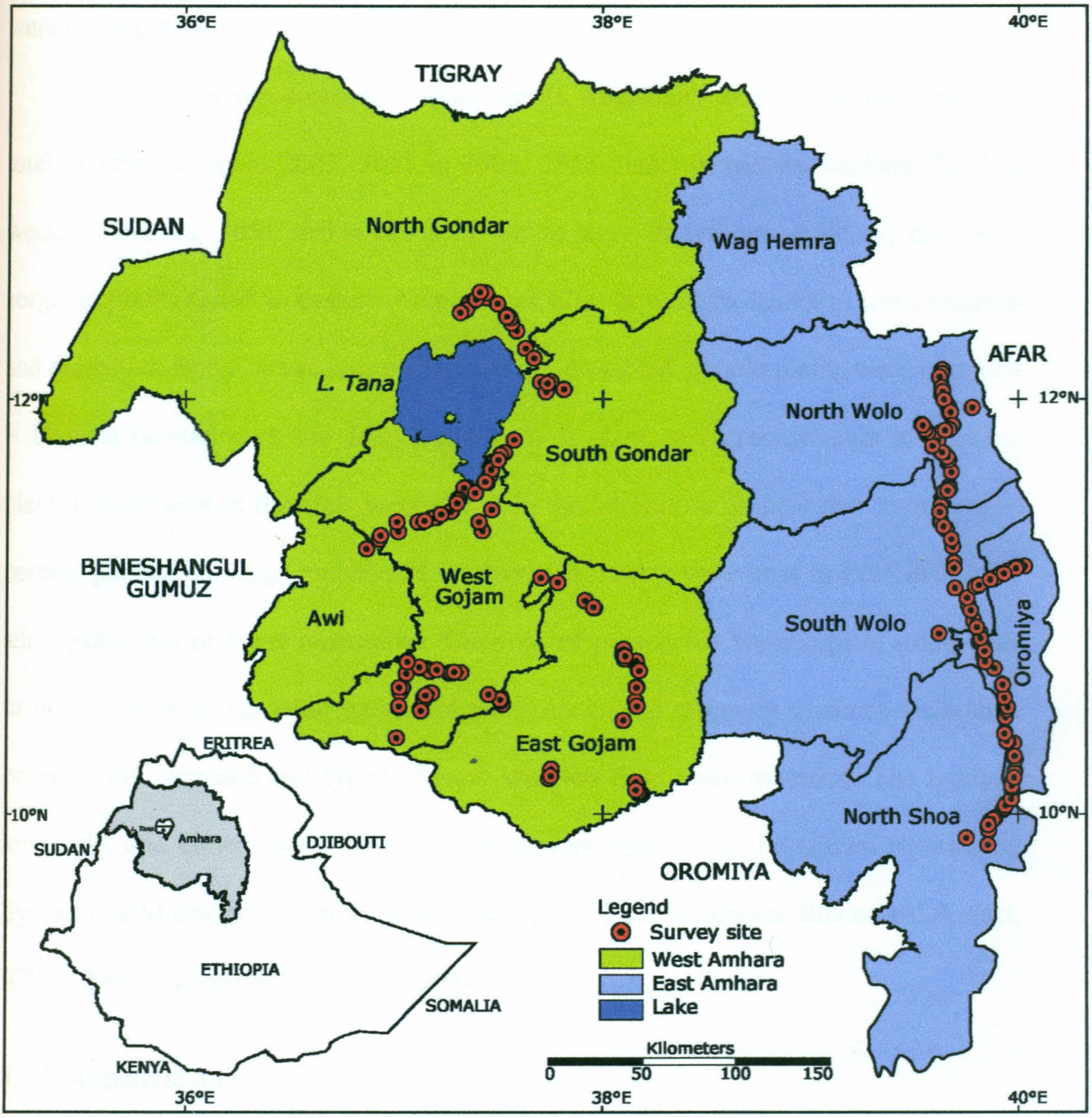


Fig. 4.1 Survey localities in the Amhara state, 2003 and 2004.

Then any of them in sight were considered as predators right away and recorded even when they were not seen attacking borers. At harvest peduncle damage (sorghum) and cob damage (maize) per plant, and grain yield from a sample of 16 m^2 piece of land were taken per field.

Apart from non-destructive assessments, destructive samplings consisting of a total of 3030 plants in 2003, 3655 in 2004, 3855 plants in eastern Amhara, 2821 in western Amhara, 1051 maize (90% of which were in western Amhara) and 5605 sorghum plants (3845 in eastern Amhara and 1760 in western Amhara) were sampled and dissected. Borer larvae recovered from the dissected sample plants were kept in 3 × 1" vials labeled with the date, location, host plant, and growth stage of the host plant. Larvae kept in the vials were reared in the laboratory on host diet to determine percent parasitism. Eggs, pupae and unidentified insects were kept in Petri dishes for adult parasitoid or borer emergence. Cocoons of parasitoids were kept in small vials or plastic capsules for adult parasitoid emergence. The cropping systems, vegetation cover of the area and soil types of each sampled field were recorded. The latitude, longitude, and elevation of the survey sites were read using the Global Positioning System (GPS) device. The biosystematics expert of the Stemborer Biocontrol Project, ICIPE, Kenya, identified some of the specimens.

4.2.3 Statistical analysis

The mixed model procedure. Analyses of variance (ANOVA) were conducted using the mixed model procedure (SAS, 1999-2000) to determine variation in borer density, natural enemies (% borer parasitism and population of predators), plant damage variables, and yield, between years, regions and zones, and crop growth stages. Locality, district, year × zone × district × locality constitute random effects, while year, zone, crop growth stage, and variety constitute fixed factors. Localities were nested within districts, districts within zones, zones within years. The percentage variance estimates for the random effects were calculated, and when the mean estimates of fixed factors were significant, they were separated using Tukey-Kramer in SAS.

Correlation analyses. Correlation analyses of altitude, plant growth stage (dummy variables, 1 for seedling, ..., 5 for harvest), plant growth parameters, borer population, parasitism, damage levels, and yield were carried out by using mean data of study localities at various growth stages of the crops.

Regression analyses. Stepwise multiple regressions were computed to estimate the contribution of plant growth parameters, borer damage, and parasitism to yield (head weight g/plant and cob weight (SAS, 1999-2000).

Logistic regression. Percentage parasitism of *C. partellus* by *C. flavipes* and internode damage by borers were analyzed by the maximum likelihood analysis using the logistic regression model of the SAS (SAS, 1999-2000) for categorical variables of zones and crop growth stages.

Dispersion analyses. Taylor's (1961) power law was used to describe the dispersion of borer larvae and pupae at different growth stages of the crop and for each borer species. The law postulates a consistent relationship for a particular species between variance S^2 and the mean $\overline{X}$:

$$S^2 = a\overline{X}^{b} \qquad (1)$$

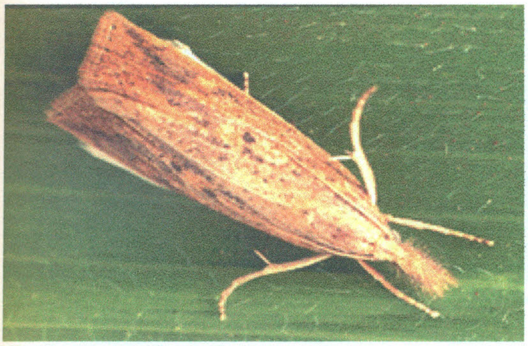
where *b* is a measure of dispersion of the species, if *b*>1, it indicates an aggregated distribution, *b* = 1 randomness, and *b* < 1 regular distribution, while *a* is considered a mere scalar factor without biological meaning. These coefficients were computed by regressing the natural logarithm of the between plant variance ($\ln S^2$) against the natural logarithm of mean density ($\ln \overline{X}$), for each crop growth stage, region, or sampling occasion. Samples where variance equals the mean and those variances equal to zero were excluded from the analysis.

Where necessary, percentage data were arcsine and counts log (x+1) transformed to stabilize the variance. The significance level was set at P=0.05.

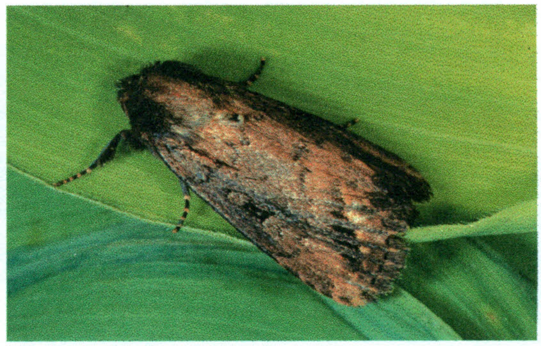
4.3 Results

4.3.1 Stemborer species composition and distribution

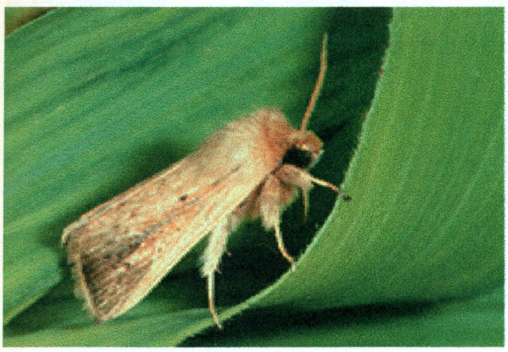
Lepidopterous and coleopterous borers were observed (Figs. 4.2 & 4.3). Across sampling periods, 12,500 borers were collected in the two agroecozones investigated. Borer density and species composition varied with region (semi-arid eastern and the cool-wet western Amhara), administrative zone, year, crop phenology, crop type and variety (Table 4.1). Of the total borers collected, 75.4% were found in semi-arid eastern (SAE) and 24.6% in the cool-wet ecozone (CWE) regions. Furthermore, 62.2% were *C. partellus*, 33.7% *B. fusca* and 4.1% were *S. calamistis*. Again, 60.2% of borers were *C. partellus* borers found on sorghum and 2% on maize; 23.2% were *B. fusca* borers on sorghum and 8% on maize; and, some 1% *S. calamistis* borers on sorghum and 3.2% on maize. In addition, 154 *R. niger* stemboring grubs and adults were collected from inside the dissected sorghum stems. In the cool-wet region, where maize was the major crop, *B. fusca* and *S. calamistis* were of similar importance, especially in areas near Lake Tana, while on sorghum, *B. fusca* was dominant and *S. calamistis* was rare. In the semi-arid region, where sorghum was the major crop, the predominant species was *C. partellus* followed by *B. fusca* and *S. calamistis* (Table 4.1).



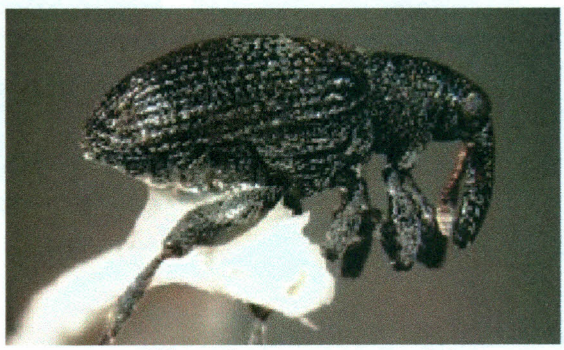
Chilo partellus adult



Busseola fusca adult

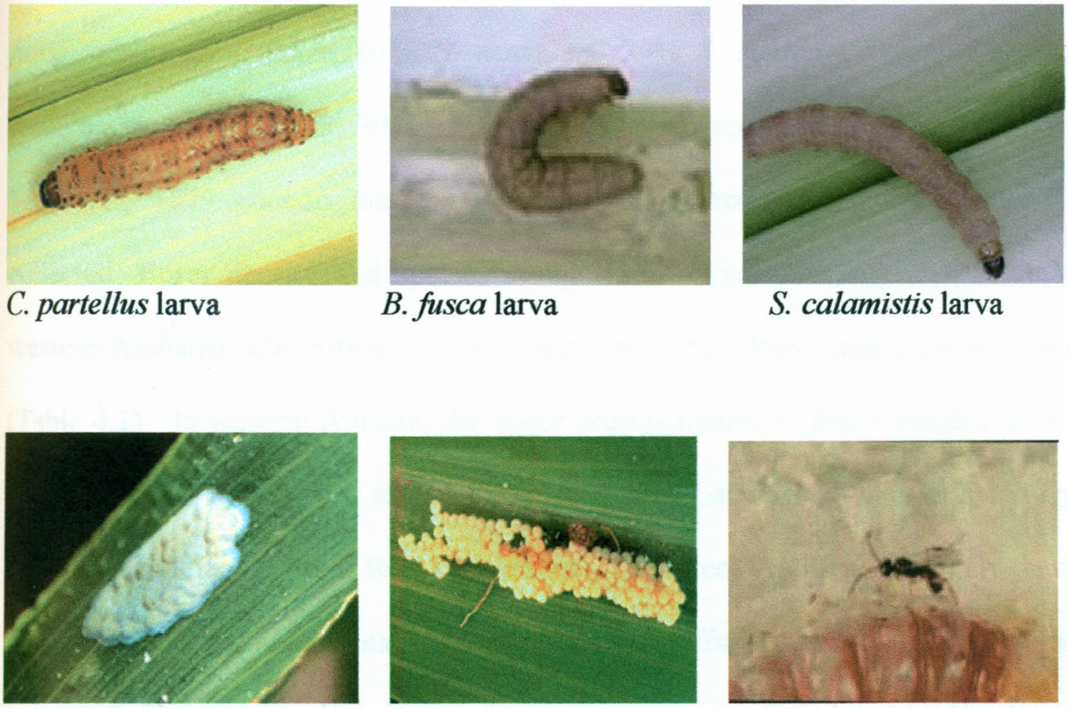


Sesamia calamistis adult



Rhynchaenus niger adult

Fig. 4.2 Stemborers found in the Amhara state attacking maize and sorghum (*Chilo partellus*, *Busseola fusca* and *Sesamia calamistis*) and sorghum (*Rhynchaenus niger*).



C. partellus larva | *B. fusca* larva | *S. calamistis* larva

C. partellus egg batch | *B. fusca* egg batch | *Cotesia flavipes* adult

Fig. 4.3 Immature stages of stemborers and an adult larval parasitoid *Cotesia flavipes*.

More or less the same species composition was observed in 2003 and 2004 (Fig. 4.4). In 2004, in eastern Amhara, on sorghum, the composition was 91% *C. partellus*, 8% *B. fusca* and 1% *S. calamistis*. In western Amhara, on sorghum, it was solidly *B. fusca*, whereas on maize, 61% *B. fusca* and 39% *S. calamistis* were recorded at tasseling stage. However, 91% of the borers were recorded to be *S. calamistis*. Moreover, 1879 cocoon masses, and 154 coleopterous larvae and adults were collected. Borer density and species composition varied with region (eastern and western Amhara), administrative zone, year, crop phenology, crop type and variety (Table 4.1). In western Amhara, the major crop is maize; *B. fusca* and *S. calamistis* were of similar importance, especially in areas near Lake Tana while in sorghum *B. fusca* was dominant with a few *S. calamistis*. In eastern Amhara, where sorghum is the major crop, the predominant species was *C. partellus* followed by *B. fusca* and *S. calamistis* (Table 4.1). Coleopteran borer, *R. niger*, was found on sorghum in both regions. *R. niger* densities were generally low but they tended to be higher in eastern Amhara. The total borer densities on sorghum tended to be higher in eastern than western Amhara and they were considerably higher in the 2003 than the 2004 season (Table 4.1). Borer density was generally higher on sorghum than on maize (Table 4.1), and borer densities increased from the seedling to the grain filling stage and then decreased at harvest. *C. partellus* dominated the Amhara state with as many as 4-fold the number of the second most important species, i.e., *B. fusca* (Table 4.1). *S. calamistis* was minor on sorghum, but despite its low density, it was the sole species on some maize fields bordering Lake Tana, West Gojam and South Gondar zones. The total borer density and *C. partellus* steadily decreased as we go north from North Shoa to North Wolo (Table 4.1). Contrary to *R. niger*, lepidopterous borer density was significantly higher on the traditional long maturing sorghum varieties than the medium and early maturing ones (Table 4.1).

For the total borer density on sorghum, random effects (Locality x District x Zone x Year), hereafter referred to as locality x D x Z x Y, contributed 36% and the residual 53% of the variation; on maize much of the variation (i.e., 76.4%) was contributed by the residual (Table 4.1). As for individual borer species, most of the variation was explained by the residual (between 56 and 94%). However, on *C. partellus* and *R. niger*, the contribution of both locality x D x Z x Y and residuals was not very different, i.e., 43% and 56% for *C. partellus* and 51% and 49% for *R. niger*.

Table 4.1 Effects of year, location and crop growth stage on abundance of borers per plant on sorghum and maize in the Amhara state, Ethiopia.

	Sorghum	Maize	Sorghum	Sorghum			Maize	
	Lepidopterous borers/ plant		*R. niger*/ plant	*C. partellus*	*B. fusca*	*S. calamistis*	*B. fusca*	*S. calamistis*
Random effects	**% Variation explained**							
Locality (D x Z x Y)*	34.0	12.9	21.1	32.6	23.5	24.7	10.4	6.1
Zone (year)	11.3	14.0	43.0	17.0	1.3	0.5	9.1	4.5
District	0.0	2.8	0.9	0.0	16.2	0.1	7.1	0.0
Residual	54.7	70.3	35.0	50.4	59.0	74.7	73.4	89.4
Fixed effects	**Least square means (±SE)**							
Year								
2003	2.34±0.46a	0.56±0.30a	0.09±0.01a	1.86±0.34a	0.50±0.11a	0.03±0.01a	0.37±0.31a	0.09±0.06a
2004	1.05±0.43b	0.01±0.33b	0.00±0.01b	0.83±0.31b	0.28±0.10b	0.01±0.01b	0.01±0.33b	0.07±0.05a
F value	15.90	13.29	89.98	12.10	6.54	9.82	16.62	0.09
P value	<.0001	0.0007	<.0001	0.0006	0.0114	0.0020	0.0002	0.7666
Administrative zone**								
East Gojam	1.23±0.75b	0.67±0.31a	0.00±0.01c	DE	0.93±0.16a	0.0030±0.01b	0.52±0.32	0.09±0.05
West Gojam	0.00±2.30c	0.28±0.25a	0.02±0.02bc	DE	0.00±0.55b	0.0003±0.06ab	0.05±0.24	0.13±0.04
South Gondar	1.37±1.36b	0.01±0.54a	0.00±0.02c	DE	0.43±0.31a	0.0100±0.02ab	0.10±0.32	0.11±0.08
North Gondar	1.77±0.84b	0.00±0.87a	0.00±0.01c	DE	0.93±0.18a	0.0100±0.01ab	0.15±0.12	0.00±0.16
North Shoa	3.18±1.10a	-	0.08±0.02b	2.94±0.49a	0.23±0.21a	0.0050±0.01b	-	-
Oromiya	2.90±0.73a	-	0.07±0.01b	2.64±0.35a	0.05±0.15b	0.0060±0.01b	-	-
South Wolo	1.97±0.65b	-	0.13±0.01a	1.78±0.37b	0.25±0.15a	0.0500±0.01a	-	-

North Wolo	1.20±0.62b	-	0.17±0.01a	1.23±0.35b	0.34±0.14a	0.0400±0.01a	-	-
F value	2.20	1.06	29.07	4.10	3.85	5.22	0.47	0.42
P value	0.0371	0.4000	<.0001	0.0292	0.0457	<.0001	0.6345	0.7415
Growth stage								
Seedling	0.55±0.44c	0.00±0.04c	0.00±0.01c	0.31±0.32d	0.25±0.11c	0.014±0.01b	0.0±0.0b	-
Knee height	2.62±0.44b	0.54±0.29ab	0.00±0.02c	2.25±0.33b	0.45±0.11b	0.010±0.01b	0.0±0.0b	0.10±0.05a
Tasseling/Flag leaf†	2.39±0.63b	0.91±0.31a	0.13±0.04a	1.78±0.51ac	0.56±0.18ac	0.023±0.02ab	0.51±0.31a	0.19±0.05a
Grain filling	3.28±0.43a	0.87±0.47a	0.08±0.01a	2.71±0.31a	0.61±0.10a	0.039±0.01a	0.01±0.53b	0.08±0.10ab
Harvest	0.88±0.43c	0.42±0.28b	0.08±0.01a	0.47±0.31cd	0.51±0.10ab	0.007±0.008b	0.44±0.28a	0.01±0.03b
F value	112.10	9.49	5.68	111.56	28.245	8.32	7.77	19.15
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Variety* **								
Long maturing	4.4±0.2a	-	0.23±0.06b	4.18±0.19a	0.17±0.01a	0.05±0.004a	-	-
Medium maturing	1.5±0.3b	-	1.26±0.18a	1.43±0.38b	0.04±0.02b	0.02±0.005b	-	-
Early maturing	1.9±0.2b	-	1.30±0.12a	1.79±0.31b	0.09±0.02b	0.03±0.007b	-	-
F value	15.74	-	28.57	34.02	15.74	15.24	-	-
P value	<.0001	-	<.0001	<.0001	<.0.0001	<.0001	-	-

† Flag leaf for sorghum and tasseling for maize; - indicates no data or minor crop status; ** 1st four zones are in western Amhara, 2nd four in eastern Amhara; *** long maturing stands for 8-9 month, medium for 6-7 month and early for 4-5 month varieties of sorghum only; DE indicates that that particular species does not occur there; Y stands for Year, Z for zone and D for district; means within a column followed by the same letter(s) are not significantly different according to Tukey-Kramer (P<0.05).

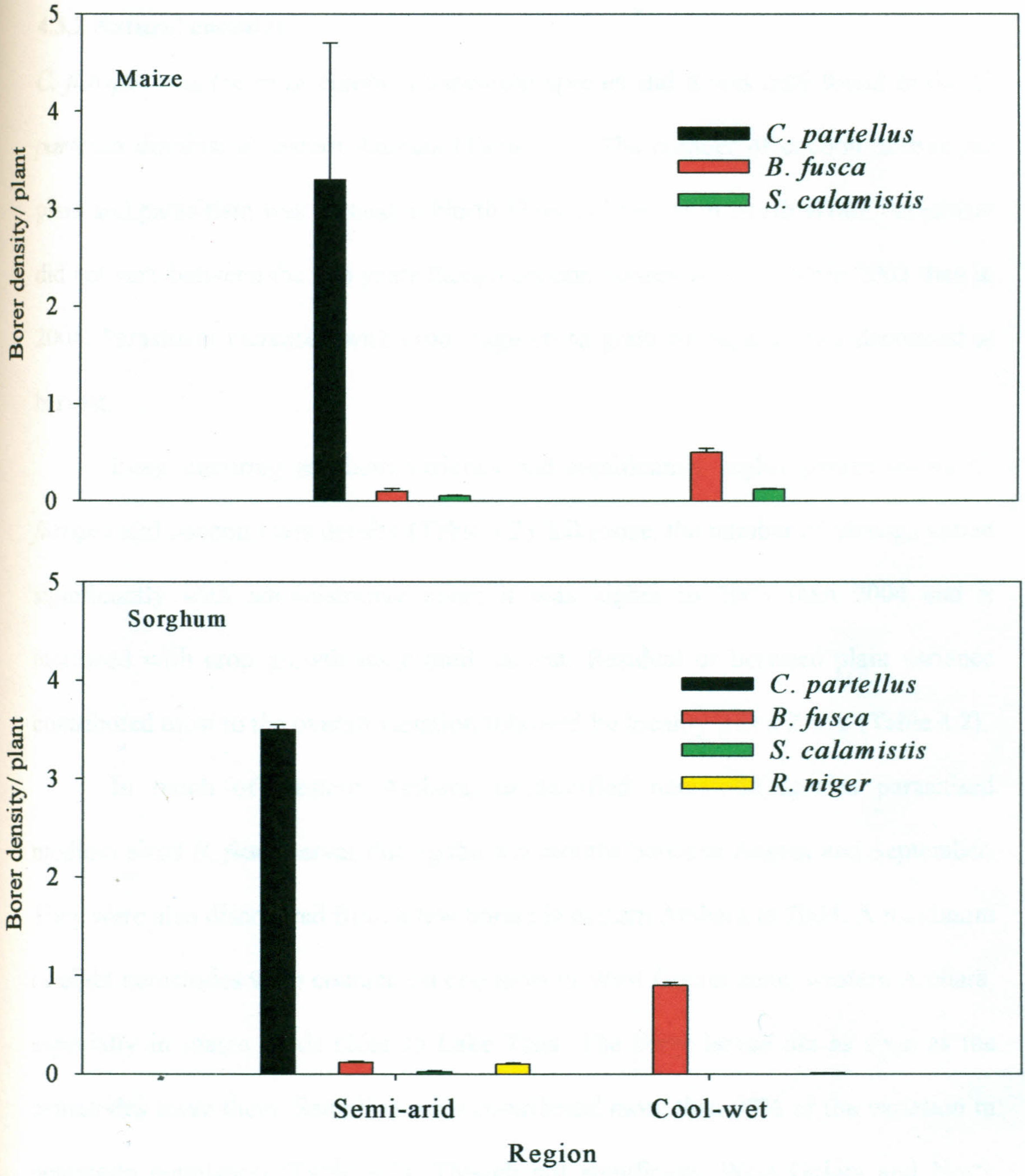


Fig. 4.4 Regional variation of species composition in the Amhara State on maize and sorghum, 2003-2004.

4.3.2 Natural enemies

C. flavipes was the most common parasitoid species and it was only found in the *C. partellus* dominated eastern Amhara (Table 4.2). The number of cocoon masses per plant and parasitism was highest in North Shoa and lowest in North Wolo. Parasitism did not vary between the two years though cocoon masses were higher in 2003 than in 2004. Parasitism increased with crop stage up to grain filling and then decreased at harvest.

Long maturing sorghum varieties had significantly higher parasitism by *C. flavipes* and cocoon mass density (Table 4.2). Likewise, the number of earwigs varied significantly with administrative zone; it was higher in 2003 than 2004 and it increased with crop growth stage until harvest. Residual or between plant variance contributed most to the overall variation followed by locality x D x Z x Y (Table 4.2).

In much of western Amhara, unidentified nematode species parasitised medium sized *B. fusca* larvae during the wet months between August and September. They were also discovered from a few borers in eastern Amhara in 2004. A maximum of eight nematodes were counted on one larva in West Gojam zone, western Amhara, especially in maize fields close to Lake Tana. The borer larvae die as soon as the nematodes leave them. Sampling error contributed more than 90% of the variation in nematode population (Table 4.2). Though not significant, West Gojam and North Gondar zones seemed to have higher nematode density per plant (Table 4.2). In addition to *C. flavipes*, ten species of parasitoids and one hyperparasitoid, *Aphanogmus fijiensis* belonging to five Hymenopteran families were recorded (Table 4.3).

Table 4.2 Effects of year, location and crop growth stage on abundance of cocoon masses and earwig density and on level of larval parasitism by *C. flavipes* and nematodes in the Amhara state, 2003 to 2004.

	Sorghum				Maize	
	Cocoon masses/ plant	% Larval parasitism	Number of earwigs/ plant	Nematodes/ plant	Nematodes/ larva	Nematodes/ plant
Random effects	**% Variation explained**					
Locality (D x Z x Y)	21.2	16.5	14.1	7.9	2.2	3.1
Zone (year)	4.9	4.6	0.6	1.8	0.2	0.0
District	2.6	1.6	0.0	0.0	0.0	0.3
Residual	71.3	77.3	85.2	90.4	97.6	96.6
Fixed effects	**Least square means (±SE)**					
Year						
2003	0.64±0.06a	8.89±2.5	0.08±0.02a	0.006±0.005	0.005±0.003	0.004±0.04
2004	0.42±0.04b	11.26±2.0	0.02±0.00b	0.008±0.005	0.002±0.004	0.001±0.05
F value	9.48	0.58	64.57	0.22	0.62	0.12
P value	<.0001	0.4480	<.0001	0.6376	0.4313	0.7271
Administrative zone						
North Shoa	0.92±0.07a	23.44±5.5a	0.03±0.01a	0.003±0.010	0.001±0.004	-
Oromiya	0.49±0.05b	18.64±4.1ab	0.03±0.01a	0.010±0.004	0.002±0.003	-
South Wolo	0.46±0.06b	16.40±3.9bc	0.07±0.01a	0.010±0.004	0.003±0.003	-
North Wolo	0.24±0.06c	16.03±3.6c	0.03±0.01a	0.003±0.004	0.001±0.003	-
East Gojam	-	-	0.00±0.02b	0.010±0.010	0.010±0.004	0.01±0.11b

West Gojam	-	-	0.00±0.01b	0.010±0.030	0.010±0.025	0.05±0.07a
South Gondar	-	-	0.00±0.03b	0.010±0.010	0.010±0.010	0.02±0.14b
North Gondar	-	-	0.00±0.02b	0.010±0.010	0.0001±0.004	0.01±0.10b
F value	19.68	6.28	8.81	0.41	0.60	5.40
P value	<.0001	0.0003	<.0001	0.8926	0.7519	0.0341
Growth stage						
Seedling	0.24±1.1b	0.00±2.67c	0.00±0.01c	0.001±0.01b	0.0004±0.004b	-
Knee height	0.10±0.2c	1.32±2.11c	0.00±0.01c	0.001±0.01b	0.0005±0.005b	0.06±0.04
Tasseling/ Flag leaf	0.52±0.3b	24.01±1.41a	0.01±0.01b	0.040±0.012a	0.0240±0.009a	0.00±0.04
Grain filling	1.24±0.13a	28.51±1.18a	0.01±0.01b	0.002±0.005b	0.0014±0.004b	0.00±0.09
Harvest	0.36±0.13b	14.80±1.37b	0.05±0.01a	0.000±0.010b	0.0000±0.004b	0.00±0.03
F value	25.24	66.74	9.14	17.38	9.82	2.17
P value	<.0001	<.0001	<.0001	<.0001	<.0001	0.0926
Variety*						
Long maturing	0.78±0.07a	16.8±1.38a	0.03±0.02b	-	-	-
Medium maturing	0.05±0.14b	1.13±2.73b	0.01±0.04b	-	-	-
Early maturing	0.54±0.11a	15.5±2.18a	0.27±0.03a	-	-	-
F value	10.97	13.37	24.59	-	-	-
P value	<.0001	<.0001	<.0001	-	-	-

* long maturing stands for 8-9 month, medium for 6-7 month and early for 4-5 month variety; means within a column followed by the same letter(s) are not significantly different according to Tukey-Kramer (P<0.05).

Table 4.3 Hymenopteran parasitoids of stemborers on cereal crops in different areas of the Amhara State, Ethiopia, in 2003 and 2004.

Family	Species	Number of specimens collected	% Parasitism*	Host borer reared from	Behavior	Sampling locality	Zone	Region
Braconidae	*Cotesia flavipes (*Cameron*)*	Thousands	29.00	*C. partellus* larvae	Gregarious	Eastern Amhara	All zones	EA
Braconidae	*Cotesia sesamaie?*	2	0.7	*B. fusca* larvae	Gregarious	Zachena	EG	WA
Braconidae	*Euvipio rufa* Szepligeti	1	0.7	*B. fusca*	*Solitary*	Chylo Mariam	NG	WA
Braconidae	*Dolichogenidea*	1	0.2	*B. fusca* larvae	Gregarious**	Addis Zemen	SG	WA
Braconidae	*Cotesia sesamaie?*	1	0.7	*B. fusca* larvae	Gregarious	Zachena	EG	WA
Braconidae	*Dolichogenidea fuscivora* Walker	1	2.2	*B. fusca*	Gregarious	Dembosgae	NG	WA
Braconidae	*Dolichogenidea fuscivora* Walker	1	2.2	*B. fusca***	-	Dembosgae	NG	WA
Braconidae	*Dolichogenidea fuscivora* Walker	1	0.2	*B. fusca*	Gregarious**	Addis Zemen	SG	WA
Ceraphronidae	*Aphanogmus fijiensis* Ferriere	1	0.7	*C. partellus*	Gregarious	Aradom, Afasash	NW	EA
Eulophidae	*Pediobius furvus* Gahan	1	2.3	CP pupa	Gregarious	Wofafranabomsa	OR	EA
Eulophidae	*Pediobius furvus* Gahan	1	1.0	CP pupa	Gregarious	Tis Abalima	SW	EA
Eulophidae	*Pediobius furvus* Gahan	1	0.4	*B. fusca* pupa	Gregarious	Sirinka	NW	EA
Ichneumonidae		1		UI pupa	Solitary	Birhala	WG	WA
Ichneumonidae		1		*B. fusca* pupa	Solitary	Choma	WG	WA
Ichneumonidae		1		*B. fusca*	Solitary	Choma	WG	WA

Ichneumonidae	*Dentichasmias busseolae* Heinrich	1	1.0	CP pupa	Solitary	Gulbo	SW	EA
Ichneumonidae	*Procerochasmias nigromaculatus* Cameron	2	1.3	*B. fusca*	Solitary	Qilazs, Dembosgae	WG, NG	WA
Ichneumonidae	*Dentichasmias busseolae* Heinrich	1	0.2	CP pupa	Solitary	Asfacho	OR	EA

* Percentage parasitism was calculated for individual survey sites, where the parasitoids were found, except for *C. flavipes* which occurred widely; **.empty cocoon masses from which adult parasitoids have emerged were discovered; EA eastern Amhara, WA western Amhara; EG stands for East Gojam, WG for West Gojam, SG for South Gondar, NG for North Gondar, NW for North Wolo, SW for South Wolo, OR for Oromiya and NS for North Shoa; UI for unidentified, CP pupa for *C. partellus* pupa; ? indicates that the identification was not confirmed by an authoritative body.

However, compared to *C. flavipes*, the rate of parasitism was exceedingly low (just below 2% in any one particular sampling field). Coleopteran, dipteran (families Chloropidae and Phoridae as scavengers), the hymenopteran family Formicidae and Isopteran families were observed attached to stemborer larvae.

4.3.3 Plant damage variables

In general, plant damage variables followed the same trend as the borer numbers. On sorghum, percentage stem tunneling, internode damaged and number of holes per plant were higher during 2003 than 2004, in eastern than western Amhara, and tended to increase with the stage of the crop (Table 4.4). There was a general trend of decrease in damage levels as we go from North Shoa northwards to North Wolo. Long maturing varieties had significantly higher damage levels. On sorghum, the random effects of locality x D x Z x Y contributed more than 35% and the residual more than 50% of the variation in damage levels (Table 4.4). On maize, only percent internode damage varied significantly with year, although in all cases damage was higher in 2003 than in 2004, while there was no difference in damage levels between administrative zones. In most cases, significantly higher damage levels were recorded at around the tasseling and grain filling stages (Table 4.4). Cob damage was generally low and non-significant and residual or between-plant variance contributed most to the overall variability followed by district (Table 4.4).

4.3.4 Yield and yield components

Head weight of sorghum and grain weight of both crops did not vary with year, while cob weight was higher in 2003 than 2004 (Table 4.5). However, yields varied significantly with administrative zone. The highest mean head weight and grain yield of sorghum and maize were obtained in North Wolo and West Gojam, respectively

Table 4.4 Effect of year, location and crop growth stage on damage variables on sorghum and maize in the Amhara state, 2003 and 2004.

	Sorghum			Maize			
	% Stem tunneling	% Internode damage	Holes/ plant	% Stem tunneling	% Internode damage	Holes/ plant	% Cob damage
	% Variation explained						
Random effects							
Locality (Y x Z x D)	32.9	45.5	37.0	16.5	23.0	25.5	11.5
Zone (year)	17.7	9.3	13.9	10.9	0.0	11.3	0.0
District	0.4	1.1	1.4	2.0	25.2	15.5	5.9
Residual	49.0	44.1	47.7	70.6	52.8	47.7	82.6
Fixed effects	**Least square means (±SE)**						
Year							
2003	13.2±2.4	24.4±3.9	6.5±1.2	7.6±1.8	24.5±5.1	4.2±1.5	0.3±1.8
2004	7.9±2.1	17.9±3.2	3.2±1.2	5.1±1.9	17.1±4.3	2.4±1.6	1.4±1.5
F value	7.20	4.93	10.89	3.73	30.66	2.65	0.35
P value	0.0081	0.0280	0.0012	0.0621	<.0001	0.1129	0.5596
Administrative zone							
East Gojam	8.3±0.5d	8.5±0.9b	0.5±0.2bc	5.4±2.0	20.7±5.5	5.3±1.7	0.3±2.23
West Gojam	0.0±0.0e	0.0±0.0c	0.0±0.0c	6.3±1.5	20.4±4.2	5.2±1.2	1.8±1.5
South Gondar	12.7±1.3cd	9.5±1.3b	0.1±0.2bc	9.3±3.8	21.4±9.2	5.5±3.2	0.6±3.1
North Gondar	21.5±0.7ab	22.8±0.8a	2.3±0.2bc	-	-	-	-
North Shoa	26.2±1.2a	40.2±1.3a	11.6±0.6a	-	-	-	-

Oromiya	18.7±0.7ac	36.0±0.9a	10.6±0.4a	-	-	-	-
South Wolo	16.9±0.7ad	31.1±0.9a	9.0±0.4a	-	-	-	-
North Wolo	10.0±0.5cd	31.2±0.8a	7.4±0.2b	-	-	-	-
F value	74.59	109.82	121.09	2.03	0.01	0.76	0.19
P value	<.0001	<.0001	<.0001	0.1297	0.9940	0.5602	0.8332
Growth stage							
Seedling	0.0±0.0d	0.00±0.0c	0.0±0.0d	-	-	-	
Knee height	3.4±0.4c	17.4±1.2b	2.4±0.3c	7.3±0.8a	-	1.5±0.3b	
Flag leaf/ Tasseling	17.8±0.9b	37.0±4.2a	7.7±0.2b	6.2±0.6ab	32.2±4.7a	4.2±0.4a	
Grain filling	22.3±0.7a	32.1±1.0a	10.3±0.4a	5.8±1.9b	26.1±4.1a	4.4±1.9a	
Harvest	19.6±0.5b	24.7±0.5b	7.3±0.2b	0.2±0.3c	9.4±4.1b	0.0±0.2c	
F value	244.69	531.70	193.26	35.65	107.44	38.78	
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	
Variety*							
Long maturing	38.6±1.16a	50.6±1.11a	20.6±0.72a	-	-	-	-
Medium maturing	21.5±2.29b	30.4±2.21b	12.1±1.43b	-	-	-	-
Early maturing	18.4±1.83b	33.1±1.76b	9.7±1.14b	-	-	-	-
F value	54.0	55.42	38.33	-	-	-	-
P value	<.0001	<.0001	<.0001	-	-	-	-

† Flag leaf for sorghum and tasseling for maize; - no data available or minor crop status in the area; maize is uncommon in North Gondar and sampling was not enough to present data; * differences in varietal length of time to maturity were more substantial in sorghum than maize; means within a column followed by the same letter(s) are not significantly different according to Tukey-Kramer (P<0.05).

(Table 4.5). Residual contributed more than 60% of the variation in sorghum head weight, but did not contribute for grain yield (Table 4.5). On maize, however, the difference in the level of contribution to the variation in both cob and grain weight was similar between the residual and locality x D x Z x Y.

4.3.5 Relationships between borers, parasitism, borer damage, plant growth variables, altitude and yield

4.3.5.1 Correlation analyses

Results of the correlation analyses carried our using the whole data of the entire study period is shown in Table 4.6. The results indicate that altitude was significantly negatively correlated to *C. partellus* population, all plant damage variables and larval parasitism by *C. flavipes*, and positively to *B. fusca* and the total borer density (Table 4.6). *C. partellus* was found as high as 1900 m, and *B. fusca* as high as 2600 m elevation (Fig. 4.5). Plant growth stage was positively correlated to plant growth parameters, damage variables, borer populations and parasitism. Similarly, plant growth parameters were all positively correlated to the borer damage, borer population, parasitism and yield. Damage variables were also positively correlated to borers and parasitism. Among the plant damage variables only tunneling had negative correlation to yield (Table 4.6). *C. partellus* population was negatively correlated to *B. fusca* population, and positively to the total borer density and parasitism. *B. fusca* was negatively correlated to parasitism and yield. Parasitism and cocoon mass density were positively correlated to yield (Table 4.6).

. Table 4.5 Effect of year and location on yield and yield components on sorghum and maize in the Amhara state, 2003-2004.

	Sorghum		Maize	
	Head weight (g/ plant)	Grain yield (kg/ ha)	Cob weight (g/ plant)	Grain weight (kg/ ha)
Random effects	**% Variation explained**			
Locality (district x zone x year)	28.3	100.0	51.7	41.0
District	12.1	0.0	0.0	0.0
Residual	59.6	0.0	48.3	59.0
Fixed effects	**Least square means (±SE)**			
Year				
2003	63.8±1.4a	1833.1±181.1	206.3±10.1a	3837.1±865.9
2004	57.9±2.1b	1891.4±228.2	167.7±9.1b	3724.6±834.3
F value	152.10	0.04	9.57	0.01
P value	<.0001	0.8472	0.0021	0.9926
Administrative zones				
East Gojam	70.2±2.9b	1932.9±340.9ab	155.9±11.8b	3438.5±234.4
West Gojam	-	1271.4±191.5b	232.0±7.6a	5913.2±367.1
South Gondar	11.0±3.9c	1321.0±334.0b	173.1±17.1b	2140.8±402.2
North Gondar	17.8±0.7c	1261.4±404.2b	*	*
North Shoa	68.2±3.9b	1721.6±475.5ab	*	*
Oromiya	67.7±2.1b	2281.1±294.6ab	*	*
South Wolo	70.8±3.0b	1668.8±336.9b	*	*
North Wolo	120.2±3.8a	2867.3±377.1a		*
F value	6.61	2.54	16.05	4.99
P value	0.0102	0.0298	<.0001	0.0561

* crop not grown or minor status; means within a column followed by the same letter(s) are not significantly different according to Tukey-Kramer (P<0.05).

Table 4.6 Pearson's correlation coefficients for altitude, plant growth parameters, damage variables, borer numbers and head weight of sorghum in eastern and western Amhara, Ethiopia, in 2003-2004.

	AL	GS	PH	SD	IN	PDI	HO	PT	CP	BF	TB	CO	PP	HW
Altitude (AL)	1													
Growth stage (GS)	-	1												
Plant height (PH)	-	0.70*	1											
Stem diameter (SD)	-	0.34*	0.50*	1										
# inter./ plant (IN)	-	0.54*	0.81*	0.75*	1									
% inter. damage (PDI)	-0.39*	0.47*	0.54*	0.40*	0.50*	1								
# holes/ plant (HO)	-0.43*	0.32*	0.46*	0.48*	0.58*	0.72*	1							
% stem tunneling (PT)	-0.43*	0.47*	0.43*	0.29*	0.49*	0.80*	0.69*	1						
C. partellus/plant (CP)	-0.45*	0.12*	0.26*	0.41*	0.32*	0.53*	0.67*	0.49*	1					
B. fusca/ plant (BF)	0.27*	0.19*	0.19*	0.04*	0.10*	0.30*	0.13*	0.33*	-0.1*	1				
Total borer/ plant (TB)	0.14*	0.14*	0.28*	0.41*	0.09*	0.58*	0.69*	0.56*	0.96*	0.26*	1			
# cocoons/ plant (CO)**	-0.18*	0.13*	0.20*	0.26*	0.28*	0.38*	0.49*	0.35*	0.50*	0.02	0.48*	1		
% parasitism (PP)**	-0.46*	0.06*	0.17*	0.20*	0.22*	0.27*	0.26*	0.22*	0.19*	-0.1*	0.16*	0.63*	1	
Head weight/plant (HW)	-	-	0.56*	0.61*	0.47*	0.10*	0.18*	-0.1*	0.15*	-0.1*	0.14*	0.06*	0.11*	1

Plant sample size was 1954; * stands for $P<0.05$; *C. flavipes* (cocoon masses) and *C. partellus* do not occur in western Amhara; **stands for cocoon masses and parasitism refer to the parasitoid *C. flavipes*; plant growth parameters include plant height, stem diameter, internodes per plant, and damage variables include tunneling, holes and internode damage.

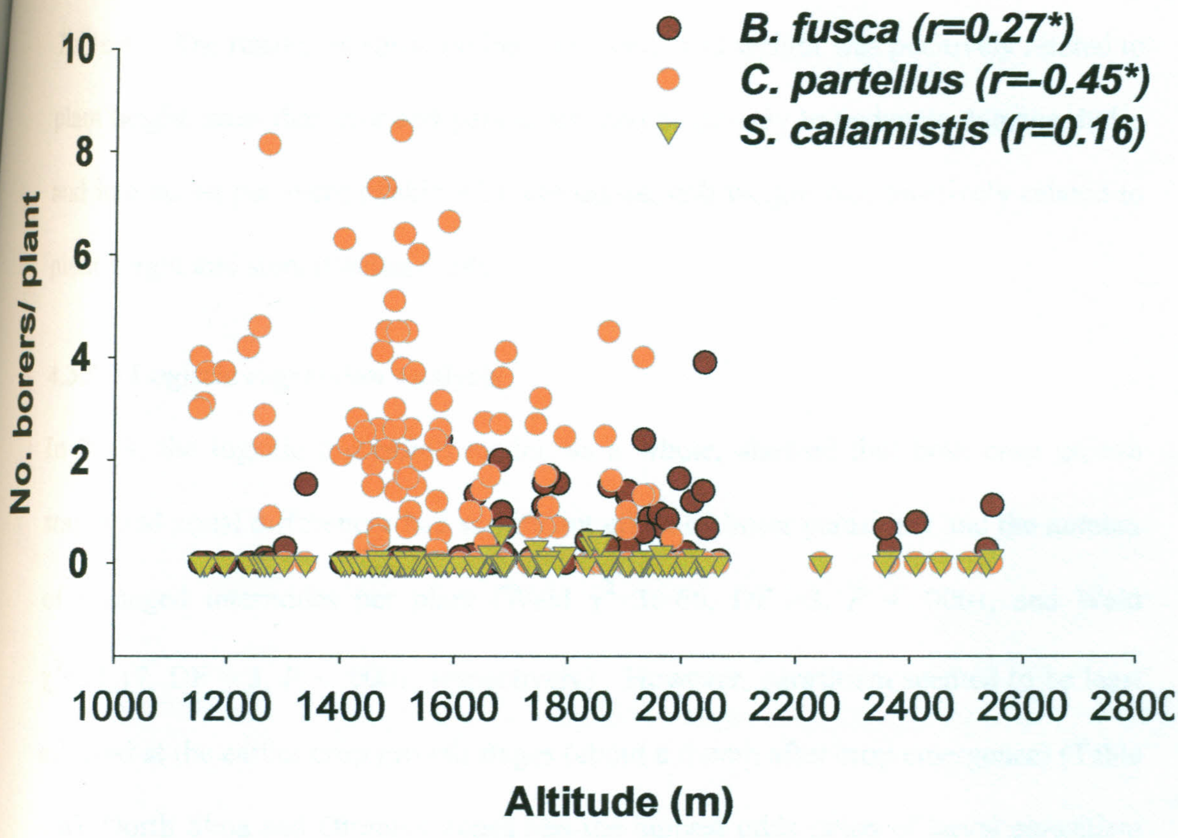


Fig. 4.5 The relationship between borer density of various species and altitude in the Amhara state.

4.3.5.2 Stepwise regression analyses

The stepwise regression analyses carried out on sorghum and maize yield against plant growth parameters, borer populations, borer damage and parasitism are given in Table 4.7. The results on sorghum indicated that head weight was positively related to plant height, stem diameter and parasitism, and negatively to peduncle damage, holes and internodes per plant (Table 4.7). On maize, cob weight was positively related to plant height and stem diameter only.

4.3.5.3 Logistic regression analysis

In 2003, the logistic regression model, as a whole, showed that both crop growth stages and zonal differences had significant effect on borer parasitism and the number of damaged internodes per plant (Wald χ^2=36.66, DF =3, $P < .0001$, and Wald χ^2=35.17, DF = 3, $P < .0001$, respectively). However, parasitism seemed to be least affected at the earlier crop growth stages (about a month after crop emergence) (Table 4.8). North Shoa and Oromiya zones had the highest odds ratios of larval parasitism and internode damage.

4.3.6 Spatial distribution of borers

Mean density and variance estimates of the totals of larvae and pupae were fitted to Taylor's power law, which provided significant regression in all cases (Table 4.9). In eastern Amhara, seedling, knee height and grain filling stages of sorghum yielded regression slopes (b) greater than 1 indicating an aggregated distribution of *C. partellus*, while harvest stage yielded a random distribution as shown by b value of 0.91 not different from 1 (Table 4.9). Aggregated distribution of *B. fusca* was apparent mostly when pooled over crop growth stages. At the seedling and grain filling stages, regression slopes b greater than 1 of *S. calamistis* suggest an aggregated distribution similar to *C. partellus*; it showed a random distribution (b=0.84) at knee height stage. Cocoon mass counts yielded b values greater than 1 all over the growth stages and hence an aggregated distribution at all growth stages.

On sorghum, Taylor's power law coefficients were calculated for only *B. fusca* for it was the commonest of borers in western Amhara. The results at the flag leaf stage gave regression slope less than 1 and harvest stage not different than 1 suggesting a more regular and random distribution of the borers at these stages, respectively (Table 4.9). On maize, a regression slope greater that 1 was obtained for *B. fusca* indicating aggregated distribution, while on *S. calamistis* the regression slope b was less than 1 indicating a regular distribution at this stage of crop growth (Table 4.9).

Table 4.7 Effect* of borer damage variables and plant growth parameters on cob weight of maize and sorghum head in the Amhara state, Ethiopia, in 2003-2004.

	b	F	P value
	Sorghum		
Y head weight (g/ plant)			
X_1 plant height (m)	28.19	73.13	<.0001
X_2 stem diameter (cm)	50.86	190.72	<.0001
X_3 internodes/ plant	-3.96	29.38	<.0001
X_4 % peduncle damage	-0.40	19.54	0.0089
X_5 % tunneling	-0.20	5.1	0.0451
X_6 # holes/ plant	-0.44	6.86	0.0358
X_7 % larval parasitism	0.13	4.42	0.0358
Intercept = -5.11, r^2 = 0.29, N = 6680			
	Maize		
Y cob weight/ plant			
X_1 plant height (g/ plant)	173.0	107.19	<.0001
X_2 stem diameter (cm)	150.53	88.21	<.0001
Intercept = -421.2, r^2 = 0.69, N = 207			

* Stepwise multiple regressions; b values are partial regression coefficients

Table 4.8 Logistic regression analysis of the effect of crop growth stage and zones on the parasitism of *C. partellus* by *C. flavipes* and internode damage due to stemborer of sorghum in eastern Amhara, Ethiopia, in 2003-2004.

Variable	DF	Parameter estimate	SE	Wald Chi-square	P-value	Odds ratio
		Parasitism				
Growth stage						
Intercept	1	0.4058				
Seedling	1	-0.0146	0.09	0.02	0.8797	0.76
Knee height	1	-0.4091	0.08	29.57	<.0001	0.51
Grain filling	1	0.1636	0.07	5.18	0.0228	0.91
Zones						
Intercept	1	-1.7781				
North Shoa	1	0.4788	0.08	33.77	<.0001	1.97
North Wolo	1	-0.3116	0.10	9.33	0.0023	0.89
Oromiya	1	0.0313	0.0728	0.19	0.6666	1.26
		Internode damage				
Zones						
Intercept	1	-0.4561				
North Shoa	1	0.1302	0.04	11.88	0.0006	1.16
North Wolo	1	-0.1519	0.04	17.78	<.0001	0.87
Oromiya	1	0.0376	0.03	1.61	0.2042	1.06

Table 4.9 Taylor's power law coefficients of borers at various growth stages of sorghum in the two regions of the Amhara state

Amphora	Crop growth stage	Intercept (log a)	Slope (b)	r^2	P >F
Eastern	**Sorghum**				
	C. partellus				
	Seedling (belg)	0.78	1.22*a	0.93	<.0001
	Knee height	0.47	1.27*a	0.84	<.0001
	Grain filling	0.49	1.10a	0.66	<.0001
	Harvest	0.22	0.91a	0.76	<.0001
	B. fusca				
	Knee height	0.65	1.27*a	0.92	<.0001
	Grain filling	-0.06	0.97a	0.48	0.0182
	Harvest	-0.09	0.53*b	0.99	<.0001
	Pooled	0.28	1.64*a	0.79	<.0001
	S. calamistis				
	Seedling	0.40	1.06b	0.88	0.0060
	Knee height	0.35	1.10b	1.00	<.0001
	Grain filling	0.63	1.27*a	0.93	<.0001
	***C. flavipes* cocoon masses**				
	Knee height	0.69	1.27*a	0.87	<.0001
	Grain filling	0.33	1.17*a	0.91	<.0001
	Harvest	0.63	1.15b	0.65	0.0027
Western	**Maize**				
	B. fusca				
	Pooled	0.34	1.10	0.66	<.0001

* Slope different from 1, F-test, P<0.001; for each species separately slopes followed with the same letter(s) are not significantly different (P=0.05).

4.4 Discussion

In the present study, three lepidopteran and one coleopteran borer were observed in the Amhara state of Ethiopia. In Ethiopia, Emana *et al.* (2001) reported four lepidopterous and two coleopterous borer species. The latter are a recent occurrence (Emana, 2002); which were observed to attack sorghum. Their economic importance is virtually unknown. They are known as flee weevils and feed by boring wild trees (Anonymous, 2000). The recent and present findings may indicate that these beetles are shifting to cultivated crops.

Levels of infestation varied significantly with year, location, growth stage, and crop type. Infestation was higher in 2003 than 2004. The first effective rainfall and the total rainfall in the planting month of June in the cool-humid western Amhara was 26-33% higher in 2003 than at the same time in 2004. This increased rainfall could have caused more diapause larvae to emerge and start infestation in 2003 than 2004 as suggested by Chabi-Olaye *et al.* (2005c). The same principle applies to the semi-arid eastern Amhara. Up to 4-fold higher borer density was observed on sorghum than maize corroborating reports by Ogwaro (1983).

Furthermore, the dominance of *B. fusca* and *C. partellus* in western and eastern Amhara, respectively, indicates the difference in climate and other environmental variables between the two regions (Assefa, 1985; Tessema, 1982). *B. fusca* and *C. partellus* occur widely in cooler (western Amhara) and warmer regions (eastern Amhara), respectively. In the present study, *S. calamistis* was observed at the vegetative stage of maize suggesting its sporadic status (Assefa, 1991), and its preference to moist habitats. Crop phenology influences *S. calamistis* incidence (Kalule *et al.*, 1997). Interestingly, Emana *et al.* (2001) reported that *S. calamistis* was not found in northern Ethiopia, which is mainly the area known as Amhara. *S.*

nonagriodes botanephaga, which according to Emana *et al.* (2001), was specifically reported from eastern Ethiopia was not found during the present study in the Amhara state. Although *S. calamistis* is very minor borer in the Amhara State, it is reported to be the key pest in eastern Ethiopia (Difabachew Belay, pers. comm.).

Correlation analyses showed that *B. fusca* preferred higher elevations. In East Gojam, western Amhara, *B. fusca* populations were found as high as 2600 m corroborating earlier studies in other parts of Ethiopia (Assefa, 1985; Emana *et al.*, 2001). *C. partellus*, on the other hand, was found to be negatively correlated to altitude, and this is in agreement with several authors who reported that *C. partellus* is a low to medium elevation borer (Ingram, 1958; Nye, 1960; Seshu Reddy, 1983; Assefa, 1985; Overholt *et al.*, 1997; Haile and Hofsvang, 2001). In eastern Amhara, it was found up to 1900 m elevation, which was similar to the reports made by Emana *et al.* (2001) in other parts of Ethiopia. In contrast, Emana *et al.* (2002) predicted that elevation plays no role in *C. partellus* distribution; where according to them only precipitation, maximum temperature and minimum temperature were the most important factors that influence its distribution. However, in the tropics temperature is strongly influenced by elevation.

About one-half of the entire western Amhara is warmer and suitable for cereal production and also for *C. partellus* survival and spread. The inhospitable cold plateau stretching north–south separating east and west Amhara prevented it from spreading to the west. Is it a matter of time before it invades western Amhara in the same token as Overholt *et al.* (1994a) suggested that *C. partellus* would eventually invade West Africa? However, *C. partellus* has been in eastern Amhara at least since an agricultural research station was set up at Kobo (North Wolo) in the 1970s. Eastern Amhara is an ideal hotspot for stemborer, in contrast to only one zone, i.e., north

Gondar, in western Amhara. Farmers in both regions stack plant residues for animal feed and construction purposes guaranteeing the steady maintenance of stemborers.

Eastern Amhara is one of the world's most troubled food deficit hotspots. Many rural people perished due to hunger in mid 1970s, mid 1980s and in the last 10 years, and famines have become ever more frequent. During this study farmers complained that drought and borers are the recurrent threats to their survival. Effective borer management could help boost production and save surplus for bad years and prevent famines.

North Gondar zone, Dembia district, is the hotspot of *B. fusca* in western Amhara. Farmers store the thin-stemmed sorghum stubble for roofing and animal feed, a practice that maintains uninterrupted borer carryover (Adesiyun and Ajayi, 1980; Assefa, 1988a, 1988b; Harris and Nwanze, 1992; Van den Berg *et al.*, 1998). During harvest the base of the plants with roots remain in the ground; dissecting these plants later showed significant borer population in Ghana (Mary Botchey, University of Cape Coast, Ghana, pers. comm.). Thus, in conditions of low alternate hosts like the Amhara state, these mechanisms may be the major ones which sustain borer survival from season to season.

Stemborers are minor pests in other zones of western Amhara (i.e., South Gondar, East and West Gojam zones). Farmers in these areas do not use residues for roofing and they plough their field thoroughly immediately after harvest and during the long dry season preventing carryover effectively. An effective control option would be to reduce the first generation of adult population by destroying the larvae in old stalks (Ingram, 1958; Kfir, 1990; Kfir *et al.*, 1989; Unnithan and Seshu Reddy, 1989). Tillage practices are viable options for *B. fusca* and *C. partellus* control in South Africa, where large areas of maize and sorghum are planted and between

90,000 and 226,000 larvae overwinter per hectare (Kfir, 1990). Slashing maize and sorghum stubble destroyed 70% of *C. partellus* and *B. fusca* populations, and additional ploughing and disking destroyed a further 24% of the pest population in sorghum and 19% in maize (Kfir *et al.*, 1989; Kfir, 1990). However, the contribution of other biological control agents (like the ubiquitous nematodes) and the climate might have played a role. Previous studies indicate that the seasonal fluctuations of *B. fusca* populations are strongly influenced by the amount and distribution of rainfall (Cardwell *et al.*, 1997; Ndemah *et al.*, 2000; Ndemah and Schulthess, 2002). Van Hamburg (1979) discussed that high rainfall caused high larval mortality. On the one hand, young larvae feeding in the whorl might drown (Ndemah *et al.*, 2003), on the other hand, sufficient soil water might increase the vigour of the plant hence increasing survival of young larvae. Farmers during the survey reported severe borer damage when there was dry spell (i.e., no drowning of small larvae) following crop emergence (Melaku Wale, unpub.). Ndemah *et al.* (2003) explained that rainfall could cause drowning of migrating first instars. Although the major planting season is June, highland sorghum can be planted early in April in some highland areas of western Amhara, and infestation is severe during the 2-month dry spell that follows plant emergence. However, the borer disappears during the rainy season (June to August) and resumes in September and October, when rains subside.

In West Gojam, *S. calamistis* takes the place of *B. fusca* on maize and not on the sorghum fields near Lake Tana. *S. calamistis* is common at around tasseling stage. Its presence diminishes with distance from the lake. Shanower *et al.* (1993) reported that maize is the best host for *S. calamistis* development and survival compared with wild grasses.

The Blue Nile gorge is more or less like eastern Amhara, 50 km wide and as long as the river (800 km in Ethiopia), which is suitable for borers. However, *B. fusca* dominates the gorge, being west of the cold plateau.

The present results showed that infestations were higher on long maturing sorghum varieties due to long exposure time to borers corroborating results by Van den Berg *et al.* (1990) and Tanzubil *et al.* (2002).

C. flavipes was the most abundant parasitoid species in semi-arid eastern Amhara with an average of up to 30%. Emana *et al.* (2001) reported the rates of around 7.5%, which indicates that parasitism is on the increase. In 1998, when Mulugeta (2001) surveyed several cereal growing areas of Ethiopia, *C. flavipes* did not exist. Probably, *C. flavipes* must have invaded Ethiopia between 1998 and 1999, from Somalia, where it was released in 1997 (Emana *et al.*, 2001; Emana *et al.*, 2003). Its advance westwards to the cool-humid western Amhara has been hindered by the physical barrier, the Western Highlands (plateau) (Fig. 4.6), that also prevents *C. partellus* from moving west. Though *C. flavipes* is very abundant in semi-arid eastern Amhara, borer populations and their effects are still high. Zhou *et al.* (2001) reported that in Coastal Kenya it took five years before *C. flavipes* had a significant effect on *C. partellus* infestations. Thereafter, borer densities decreased by around 70%. Larval parasitism tended to be higher on long maturing varieties. Molecular analysis of the Kenyan and Ethiopian strains of *C. flavipes* indicated exact replica (Yoseph Assefa, KwaZulu-Natal University, South Africa, unpub.). The parasitoid might be released in western Amhara in order to see whether or not it could get established, although the naturally associated host, *C. partellus*, does not exist there. Abadi *et al.* (1994) reported the occurrence of *C. partellus* in far western hot humid lowland plains of the Amhara state or the Benishangul-Gumuz state, both areas bordering Sudan, which justify the feasibility of the parasitoid. *C. flavipes* is very abundant in eastern Amhara, but borer population and damage is still high, suggesting its low impact on borers. Its survival mechanism is not well understood but it might not fit with the long maturing sorghum varieties that are predominant in eastern Amhara (Fritz Schulthess, pers. comm.).

Although none of them had significant population (just between 0 and 2% parasitism), several indigenous larval and pupal parasitoids were observed in the present study. Earlier reports on the level of indigenous parasitoids in Ethiopia vary considerably, i.e., less than 1.2% parasitism (Emana *et al.*, 2001), 25% parasitism of *B. fusca* by *C. sesamiae* (Assefa, 1985) and higher than 25% (Mulugeta, 2001). Interestingly, Kfir (1995) reported 90% parasitism of *B. fusca* by *C. sesamiae* in South Africa. Such high levels of parasitism by *C. sesamiae* were not observed during the present work. Pupal parasitoids and hyperparasitoids were observed still at lower frequencies. The geographic distribution of parasitoids also varies. Mulugeta (2001) reported the occurrence of *C. sesamiae* and *Pediobius furvus* in eastern Amhara; and *C. sesamiae*, *Pediobius furvus* (Gahan) and *Procerochasmias nigromaculatus* (Cameron) (Ichneumonidae) in western Amhara. Kfir (1992) reported 100 % pupal parasitism (*Dentichasmias busseolae*, *Pediobius furvus*), and up to 80% larval parasitism, a parasitism level that was never observed at the present study. The specific reason for the low parasitism level is subject for investigation. Speculations can go that in eastern Amhara, *C. flavipes* has displaced the indigenous parasitoids, while in western Amhara, it could be associated to the low borer occurrence.

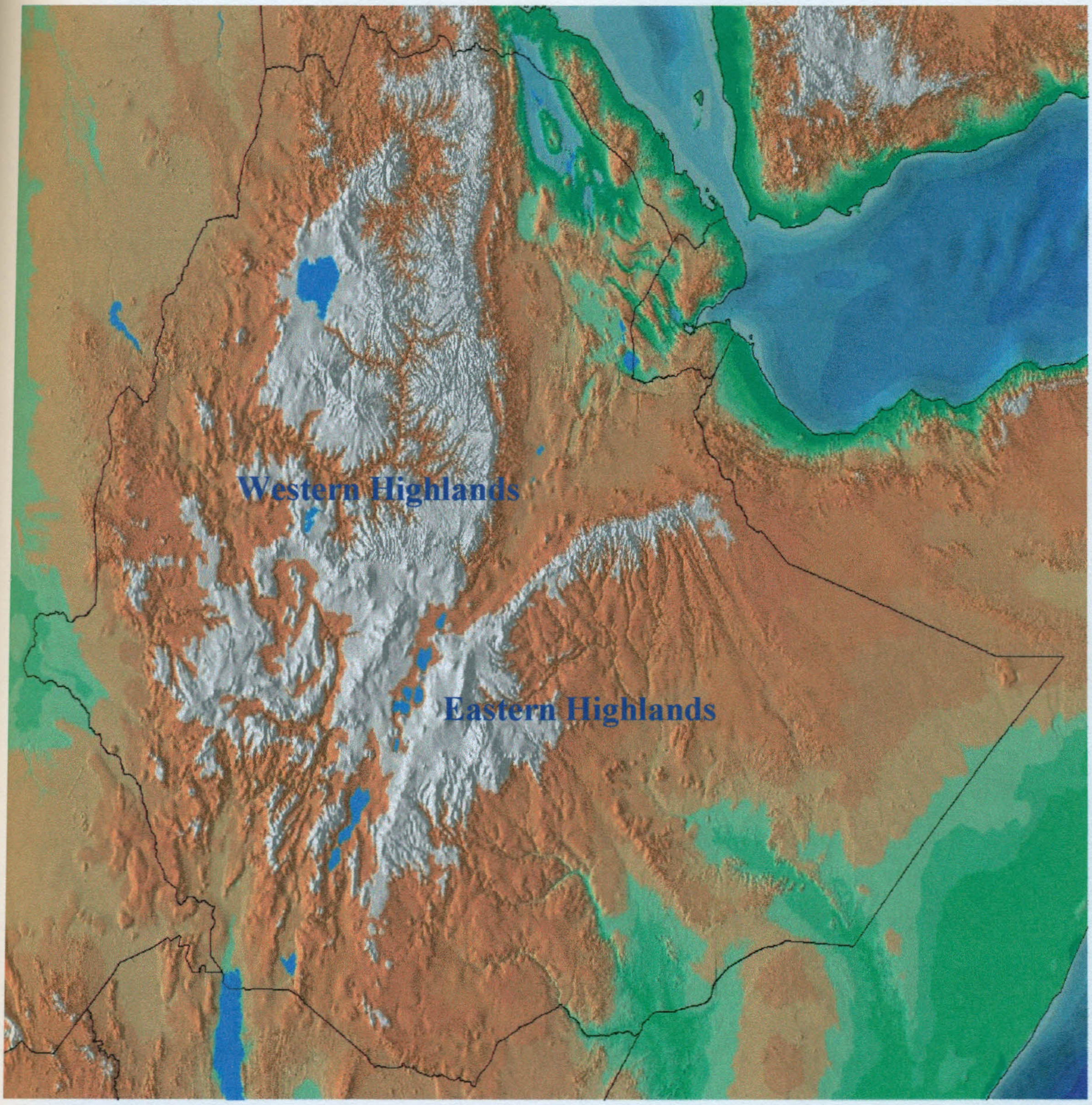


Fig. 4.6 The Ethiopian Rift Valley, which is wide in the north and narrow strip in the south, divides Western and Eastern Highlands (shaded in gray). The Western Highlands (plateau) acted as natural barrier against C. partellus and C. flavipes jump to the west.

As it happens everywhere, nematodes were observed during the wet months in western Amhara (Kaya and Gaugler, 1993; Poinar, Jr and Polaszek, 1998). The main rainy season runs from June to September. Plants grow old enough to support stemborer larvae in August and afterwards. Thus, nematodes follow borers in August and continue a bit to the drier September and vanish as an extended desiccation starts. They are generally characterized by their affinity to abundant moisture and were thus recorded mainly in western Amhara where moisture during the rainy season was abundant. They were commonly found parasitizing *B. fusca*. Similarly, Emana *et al.* (2001) reported higher nematode (*Steinernema intermedia)* density on *B. fusca* than on other borer species. Although at lower densities, Emana *et al.* (2001) reported the occurrence of nematodes *Panagro laminus* and *Hexamermis* sp. on *C. partellus* and *Heterorhabditis* sp. on *S. calamistis*. The drought prone eastern Amhara could not be an ideal habitat for nematodes, except at a few specific localities that fit the needs of the parasite. Having discovered their commonness in western Amhara, they may have contributed to low borer incidence in the area.

Both crop damage symptoms and grain yields were higher in eastern Amhara than in western Amhara. The sorghum varieties in eastern Amhara were more robust, and the heavy tillering, and better soil fertility and longer growing period (more time for grain filling) compensated for the heavy damage. In North Wolo, Gedober area, varieties grew tall and suffered less borer damage (low *C. partellus* pressure, due to relatively cooler weather) and yield was high. In Oromiya or North Shoa, the same varieties grew, but heavy borer pressure, lack of moisture, and excessive heat reduced the yield significantly. In North Gondar, the sorghum varieties had a multitude of problems: thin-stemmed and stunted, borer pressure and water-logging caused the lowest yield recorded.

Yields were positively correlated to plant growth parameters but negatively to tunneling, and regressions showed negative relation between yield and holes and peduncle damage. Taller plants of maize and sorghum gave higher grain yield than short ones (Ogwaro, 1983). A number of researchers have reported the relationship between yield and damage. Stem tunnelling is accepted to be a good indicator of the degree of plant damage and, thus, yield loss (Bosque-Perez and Mareck, 1991; Van den Berg *et al.*, 1991; Kalule *et al.*, 1994; Setamou *et al.*, 1995; Kalule *et al.*, 1997; Songa *et al.*, 2001; Ndemah and Schulthess, 2002; Chabi-Olaye *et al.*, 2005b). Whereas, in Nigeria, on sorghum, Macfarlane (1990) reported that percentage damage of internodes had more consistent negative relationship than tunneling to grain yield due to *B. fusca*. Yields were also negatively related to *B. fusca* larval density corroborating previous reports (Ndemah & Schulthess, 2002; Chabi-Olaye *et al.*, 2005a). In contrast, Ndemah *et al.* (2001a) reported no relationship between cob yield and borers because until harvest many of the borers migrate, reach adulthood, or get killed by natural enemies.

The present study indicated that the between-plant distribution of borers, i.e., total of larval and pupal numbers, showed varying dispersions with crop growth stage. Generally, *C. partellus* and *S. calamistis* larvae and pupae had aggregated distribution corroborating reports by Overholt *et al.* (1994b) and Schulthess *et al.* (1991), respectively. *B. fusca* larvae and pupae, pooled over crop growth stages, had aggregated distribution, though it did not show this trend in all individual growth stages. Deviation of some growth stages from the aggregated distribution may perhaps be due to the influence of pupal rather than larval population. Likewise, in Cameroon, Ndemah *et al.* (2001b) reported random distribution of *B. fusca* eggs, diapausing larvae and pupae, while other stages were aggregated. Also, Overholt *et al.*

(1994b) reported that aggregations of *C. partellus* became progressively less aggregated as insects aged, indicating probably the situation which was observed on aging crop plants in the current study.

The current study showed that stemborer species complex was more or less similar to earlier reports (Ferdu *et al.*, 2001; Shegaw *et al.*, 1999; Emana *et al.*, 2002), except that *S. calamistis* was found to be the species found in the vicinity of Lake Tana, albeit at relatively lower frequencies. Borer infestation decreased and grain yield increased northward in eastern Amhara. Hotspots for stemborer infestation are the whole of eastern Amhara, North Gondar zone and the Nile gorge of western Amhara. Comparing eastern and western Amhara, damage caused by borers was most severe in eastern Amhara, although crop yield was still higher due to tolerance of traditional sorghum varieties and better soil fertility. The current study showed that *C. flavipes* spread and level of parasitism was much higher than previous reports (Emana *et al.*, 2001). On the contrary, the occurrence of indigenous parasitoids was far lower than earlier estimates (Assefa, 1985; Mulugeta, 2001). *C. flavipes* may be released in western Amhara for establishment.

In conclusion, since the present study confirmed the high status and wide distribution of *C. partellus* and *B. fusca* in the state, future efforts of borer management should be targeted on them. The exotic parasitoid *C. flavipes* proved successful. Impact assessment and supplementary release in isolated areas like western Amhara, and investigations on mechanisms for the low occurrence of borers in much of western Amhara are suggested.

CHAPTER FIVE

EFFECT OF DIFFERENT RATES OF NITROGEN FERTILIZATION ON LEPIDOPTEROUS STEMBORERS AND YIELD LOSSES ON MAIZE AND SORGHUM IN THE AMHARA STATE OF ETHIOPIA

5.1 Introduction

In Africa, over 42 million tons of maize and 20 million tons of sorghum were produced in 2002 (FAO, 2003). In Ethiopia, maize and sorghum are grown on 2.4 million hectares (CSA, 2000; CACC, 2003), contributing about 41% of the country's annual grain production. Although maize grows from 500 to 2,400 m a.s.l. (Friew and Girma, 2001), it thrives best in relatively wet and intermediate altitudes (1500-2000 m a.s.l.). Sorghum is the dominant crop in lowlands (<1500 m a.s.l.), where drought and poor harvest are common (Birhane, 1977). One of the major biotic constraints to cereal production in Ethiopia is lepidopterous stemborers such as the invasive crambid *Chilo partellus* (Swinhoe) and the noctuid *Busseola fusca* (Fuller) (Assefa, 1985). Yield losses vary with crop and borer species as well as agro-ecosystem and they range from 15-100% (Assefa, 1989; Tadesse, 1989; Gashawbeza and Melaku, 1996; Emana, 1998b). Besides stemborers, low soil fertility, and especially nitrogen deficiency, is a major constraint to cereal production in the country (Emana, 2002). As shown by various authors (Setamou *et al.*, 1995; Chabi-Olaye *et al.*, 2005a; Mgoo, 2005) nitrogen not only increases survival of young stemborer larvae and thereby pest infestations but it also enhances the plant's tolerance to stemborer attacks.

Previous stemborer research in Ethiopia concentrated in the central and southern Rift valley and eastern parts of the country (Birhane, 1977; Assefa, 1985; Emana, 1998a, 1998b; Melaku, 1999; Emana, 2002). Though the Amhara State is second in maize and first in sorghum production in Ethiopia (BOA, 1999, CACC, 2003), little is known about the pest status of stemborers in the region. In addition, the exotic parasitoid *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) was reported from eastern Amhara (Emana *et al.*, 2003). This parasitoid was introduced in 1993 into Kenya (Overholt *et al.*, 1994a) by the International Centre of Insect Physiology and Ecology (ICIPE) as part of a classical biological control program now encompassing eleven countries in East and Southern Africa. *C. flavipes* has invaded Ethiopia probably from Somalia where it was introduced in 1997 (C. Omwega, ICIPE, Kenya, pers. comm.). Improving soil fertility complements pest control measures (Saroja *et al.*, 1987). Reports from western Africa show that the nutritional status of maize affects densities of *B. fusca* as well as the plant's ability to compensate for pest damage. By contrast, there is no information on how soil nutrients, and especially nitrogen, influence these tri-trophic interactions in cereal systems in East Africa. The response of stemborers in East Africa, including the dominant *C. partellus*, to these nutrients is literally unknown. Chemical fertilizers, and especially nitrogen, are commonly used in the cool-wet ecozone, and to a lesser extent in semi-arid ecozone of the Amhara state, but it is not known how they affect borer densities and yields of cereals in these regions. The present study elucidates the effect of different N levels on borer incidence, the performance of natural enemies as well as on yields of maize and sorghum, in two agro-ecozones of the Amhara State of Ethiopia.

5.2 Materials and methods

The study was conducted in the main season, i.e., from June 2004 to January 2005, in the Amhara National Regional State (ANRS), located in northwestern and northeastern Ethiopia. Trials were planted in Kola Diba and Addis Zemen in western and Chefa in eastern Amhara. Geographic and climatic information, soil characteristics of trial sites, planting and harvest time as well as the predominant stemborer species are given in Tables 5.1a and 5.1b.

5.2.1 Western Amhara

There is one rainy season in western Amhara that runs from June to November, with the wettest months from June to September. Maize is the most important cereal crop followed by sorghum. In the maize dominated zones and especially West Gojam, stemborers are not a problem, thus the trials were planted in hot-spot areas in Kola Diba and Addis Zemen, where sorghum is the dominant crop.

The 145-day maize hybrid *BH* 540 and the 175-day sorghum variety *Birmash* were planted at a spacing of 0.75 and 0.30 m between and within rows, respectively. Plot size was 36 m^2, and spacings between replications and plots were 3 and 2 m, respectively. The trials were arranged in a split-plot design, replicated 4 times. Four nitrogen fertilizer levels and two insecticide treatments (treated and untreated) represented mainplots and subplots, respectively. The four fertilizer levels for maize were 0, 60, 120, 180 kg N ha^{-1}, while for sorghum they were 0, 41, 64, and 87 kg N ha^{-1}. Rates were determined based on agronomic recommendations, i.e., including sub-optimal, optimal and higher than optimal levels of nitrogen, for each crop species in the area (Alemayehu Assefa, Bahir Dar, Ethiopia, person. comm.). They are herewith referred to as N_0, N_1, N_2 and N_3, respectively. Phosphorus as P_2O_5 was applied all at planting at a rate of 92 kg ha^{-1} to maize and 46 kg ha^{-1} to sorghum. N was applied as DAP (dia -ammonium phosphate) at planting and urea as side dressing at knee height and tasseling/flag leaf.

Table 5.1 Trial site characterization, Amhara State, Ethiopia.

a) Geographic locations and some physiographic details of experimental sites.

Location	Latitude	Longitude	Altitude (m)	Soil type	Drainage	Precipitation (mm)	Climate	Major species	Planting date	Harvest date
Kola Diba	12°25'04"N	37°19'00"E	1842	vertisol	Waterlogged	930.7	Wet	*B. fusca*	15 June	end Nov
Kola Diba	12°26'38"N	37°57'15"E	1961	nitosol	well drained	930.7	Wet	*B. fusca*	17 June	Mid Dec
Addis Zemen	12°04'07"N	37°43'41"E	1830	nitosols	well drained	745.1	Wet	*B. fusca*	21 June	end Nov
Chefa	10°51'20"N	39°48'56"E	1479	vertisol	Waterlogged	658.8*	Semi-arid	*C. partellus*	14 July	end Nov

* The main season only from May to December; A. Zemen stands for Addis Zemen; 3-w stands for 3rd week.

b) Soil physicochemical characteristics of trial sites (0-20 cm soil depth)

Region	District	Site	pH	Total N (%)	Available P (ppm)	Organic carbon (%)	Clay (%)	Silt (%)	Sand (%)	Textural class
Western Amphora	Kola Diba	Chylo Mariam	6.7	0.147	3.82	1.716	44	38	18	Clay
	Kola Diba	Dembosgae	7.5	0.095	22.56	1.157	46	28	26	Clay
	Addis Zemen	Yifag	6.5	0.133	4.64	1.516	40	36	24	Clay
Eastern Amhara	Chefa	Chefa	6.5	0.170	29.42	2.242	58	22	20	Clay

The insecticide cyhalothrin 5% e.c. was applied at a rate of 16 g a.i. ha^{-1} at 2, 4, 6 and 8 weeks after crop emergence using a knapsack sprayer. Two rows of high growing 'niger seed' *Guizotia abyssinica* (L.f.) Cass. (Asteraceae) were planted as guard rows around each plot to prevent insecticide drift. A plastic sheet, 2 m height and 20 m long, enough to cover the 6 × 6 m plot on all sides, was used to prevent drift during the time the guard rows were too short to prevent drift.

5.2.2 Eastern Amhara

In eastern Amhara, there are two distinct rainy periods, a short unreliable one from around January to May, onset of rainfall depending on specific location and season, and a major season from July to September. Traditionally, farmers commonly plant long duration varieties in April, which mature in December, thus, allowing for several generations of the pest on the same crop. However, farmers are increasingly switching to sorghum and maize varieties that mature in 90-120 days due to frequent early cessation of rainfall.

The experimental procedures were the same as in western Amhara but the sorghum variety was *Yeju* and the maize variety *Katumani*, both adapted to semi-arid conditions. Both sorghum and maize trials were part of a 5 ha experimental field. Because of the shorter cropping cycle (i.e., July to November), as opposed to June to December in western Amhara, insecticide treatments were carried out at 2, 4, and 6 weeks after crop emergence only.

5.2.3 Sampling procedures

Sampling was carried out at the seedling stage, knee height, flag leaf, heading (sorghum), tasseling (maize), grain filling and maturity/harvest. Ten plants were randomly chosen from the two outermost rows on each side of the plot and cut at ground level and dissected for determination of borer numbers according to species and other natural enemies (parasitoids, predators such as ants and earwigs). The borers were kept in the laboratory for adult moth or parasitoid emergence. Plant height and basal diameter, number of internodes and holes per plant, percent stem tunnelling, internodes bored, peduncle damage, head chaffyness, and cob damage were recorded

For plant nutrient analysis, 20 leaves were randomly sampled from plants in each plot at early tasseling for maize and flag leaf stage for sorghum. The fresh leaf biomass samples were kept in paper bags and first air dried under shade, then chopped and further dried in the oven at 70°C before N content analysis. The dried samples were ground to pass through a 0.5 mm mesh and their N concentration determined. Samples were digested according to Novozamsky *et al.* (1983), and total N was determined with an ammonium sensitive electrode (Power *et al.*, 1981).

All plants in the central six rows (27 m^2) in each plot were harvested to determine head weight or cob weight per plant, 1000-grain weight and grain yield per plot.

5.2.4 Statistical analysis

Analysis was done separately for each region (eastern and western Amhara) because the spectrum of borer species and ecological setting were different. An analysis of variance (ANOVA) was conducted using the general linear model (GLM) procedure (SAS, 1999-2000) to assess the effects of nitrogen fertilizer and insecticide application on pest variables, parasitism and yield components. Grain yield was converted from per plot to per ha basis for analysis. Least square means were separated using the Student Newman-Keuls (SNK) test at P = 0.05. Borer density and damage symptoms were compared between fertilizer levels and insecticide treatments. For each N fertilizer level, grain yield losses due to stemborers were assessed per hectare basis by comparing the insecticide treated plots against the untreated ones, calculated as percentage difference. Yield increases due to nitrogen fertilizer were computed as the percentage differences between N_0 and N_{1-3}.

Multiple regressions were used to evaluate the contribution of biotic and abiotic variables as well as treatments, i.e., nitrogen fertilizer levels, and insecticide application (dummy variables, 1=untreated, 2=treated) to both yield as well as borer densities. Simple linear regressions were performed between leaf N concentration and borer density (SAS, 1999-2000). Data lacking normal distribution were transformed. Percentage data were arcsine and counts log (x+1) transformed to stabilize variance. Significance was set at P=0.05 for all analyses.

5.3 Results

5.3.1 Effect of N fertilizer on leaf N content

Mean percent leaf N content significantly increased with increasing N dosages especially at Kola Diba on both maize and sorghum (Table 5.2). Increasing level of N fertilizer tended to eliminate differences in leaf N content between maize and sorghum (Table 5.2).

Table 5.2 Mean percent nitrogen (N) concentration in the leaves of maize and sorghum plants subjected to different nitrogen treatments (N_0-N_3).

	Addis Zemen	Kola Diba	
N fertilizer level	Maize	Maize	Sorghum
N_0	0.95±0.06b	0.82±0.07cB	1.19±0.07bA
N_1	0.91±0.06b	0.92±0.03cB	1.35±0.07abA
N_2	1.12±0.10b	1.21±0.10bA	1.40±0.05abA
N_3	1.38±0.10a	1.48±0.04aA	1.49±0.06aA
F value	7.12	21.25	3.95
P value	0.0011	<0.0001	0.0182

Means within a column followed by the same lower case letter and within a row within Kola Diba followed by the same upper case letters are not significantly different at $P \leq 0.05$ (SNK).

5.3.2 Effect of N fertilizer on abundance of borers

B. fusca was the dominant species in western and *C. partellus* in eastern Amhara. On sorghum at Kola Diba, *B. fusca* density tended to increase with increasing level of fertilizer on insecticide-free plots (Table 5.3a). On maize, at both Kola Diba and Addis Zemen, the trend was similar, though not significant ($F=2.50$, $P=0.06$ and $F=2.49$, $P=0.06$, respectively). For both crops in Chefa, there was no discernable trend between fertilizer application and *C. partellus* numbers (Table 5.3a). *Rhynchaenus niger* (Horn) (Coleoptera: Rhynchophoridae) (mean 0.02±0.01, range 0-3 beetles/ plant) was obtained from sorghum stems at Kola Diba but there was no effect of N fertilizer level ($F=0.51$, $P=0.6815$). On both crops and for most N treatments, insecticide application significantly reduced borer population (Table 5.3a) including *R. niger* at Kola Diba ($F = 5.1$, $P = 0.0348$); in some of the N_0 and N_1 treatments, and especially at low pest densities, the insecticide had no effect. Pest infestations were higher on sorghum than on maize, at both Kola Diba and Chefa (Table 5.3a). In all sites, there was significant three-way interaction between N fertilizer, insecticide treatments and growth stage on borer density (i.e., at Kola Diba on maize, $F = 6.2$, $P<.0001$; on sorghum $F = 70.32$, $P<.0001$; at Addis Zemen on maize, $F = 63.4$, $P<.0001$; at Chefa on maize, $F = 4.2$, $P<.0001$, on sorghum, $F = 2.59$, $P = 0.0044$). In general, borer populations significantly increased with phenological stage up to grain filling, but declined at harvest especially on maize (Table 5.3b).

Table 5.3 Least square means (±SE) of *B. fusca* density per plant at Kola Diba, Addis Zemen (both western Amhara), and *Ch partellus* at Chefa (eastern Amhara) at different levels of nitrogen fertilizer and insecticide application and at different phenological stages of maize and sorghum.

a) Effect of N fertilizer levels on borer density

N level	Kola Diba				Addis Zemen		Chefa			
	Sorghum		Maize		Maize		Sorghum		Maize	
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
N_0	0.1±0.034aA	0.2±0.1dA	0.01±0.01aA	0.1±0.1aA	0.02±0.00aA	0.1±0.1aA	0.3±0.16aB	2.6±0.4aA	0.1±0.03aB	0.4±0.13aA
N_1	0.2±0.07aB	1.5±0.1cA	0.00±0.00aA	0.2±0.1aA	0.05±0.05aA	0.4±0.1aA	0.4±0.12aB	3.7±0.4aA	0.1±0.04aB	0.5±0.13aA
N_2	0.2±0.07aB	3.0±0.2aA	0.02±0.02aB	0.4±0.1aA	0.06±0.06aB	0.7±0.2aA	0.2±0.06aB	2.8±0.3aA	0.0±0.00aB	0.4±0.12aA
N_3	0.2±0.06aB	2.1±0.2bA	0.00±0.00aB	0.4±0.2aA	0.05±0.05aB	0.8±0.3aA	0.2±0.10aB	3.5±0.4aA	0.0±0.00aB	0.4±0.13aA
F	0.97	65.50	1.38	2.50	0.76	2.49	0.85	2.34	1.24	0.19
P	0.4074	<.0001	0.2487	0.0619	0.5180	0.0643	0.4684	0.0754	0.2959	0.8991

Means within rows within a particular location and crop type followed by the same upper case letter and those means within a column within a particular treatment followed by the same lower case letter are not significantly different at P≤0.05 (SNK); F and P stand for F and P value.

b) Effect of phenological stages on borer density

Growth stage	Western Amhara		Eastern Amhara	
	Maize	Sorghum	Maize	Sorghum
Seedling	0.0±0.0c	0.0±1.37b	0.0±0.0c	0.0±0.0c
Flag leaf/Tassel	0.13±0.02a	0.21±0.14b	1.17±0.11a	2.0±0.16b
Heading/Grain fill	0.14±0.02a	1.61±0.08a	2.00±0.12a	2.5±0.16a
Harvest	0.05±0.10b	1.50±0.08a	0.50±0.11b	1.7±0.16a
F value	23.45	31.11	4.41	3.68
P value	<.0001	<.0001	0.0129	0.0310

Means within a column followed by the same lower case letter are not significantly different at P≤0.05 (SNK).

5.3.3 Effect of N fertilizer on borer natural enemies

Larval parasitism by *C. flavipes* was low and was observed only in eastern Amhara. On maize, parasitism gradually increased with the level of nitrogen treatment from 2 to 7.4% though the differences were not significant (Table 5.4). Insecticide applications significantly reduced parasitism on maize. It also increased with plant growth stage on both maize ($F=23.58$, $P< 0.0001$) and sorghum ($F=10.17$, $P=0.0015$).

In addition, the *Procerochasmias nigromaculatus* (Cameron) (Ichneumonidae) and the braconids *Dolichogenidea fuscivora* Walker and *Euvipio rufa* Szepligeti were each found once in western Amhara. Earwigs and ants were the most widespread predators of *B. fusca*. Earwigs increased with phenological stage ($F=2.45$, $P=0.0442$) and the insecticide treatment reduced their number significantly ($F=4.34$, $P=0436$), while N fertilizer had no effect ($F=0.68$, $P=0.5702$).

5.3.4 Effect of N fertilizer on borer damage variables

At Kola Diba in untreated plots, internode damage, percent stem tunneled and number of holes bored on sorghum tended to be lowest in N_0 and highest in N_3; the same trend was observed for stem tunneling at Chefa (Table 5.5). There were no discernable trends for maize.

Insecticide application, in general, reduced stemborer damage but the differences were more often significant on sorghum than maize. Damage symptoms significantly increased with phenological stage on both crops in all locations.

5.3.5 Effect of N on grain yield, head weight, cob weight and yield loss

On sorghum, stemborers caused between 16 and 47% reductions in head and 18-49% in grain weights; and the losses generally were higher in Kola Diba than Chefa (Table 5.6). In Kola Diba, the highest loss was recorded in unfertilized plots, and it showed decreasing trend with increasing N level (Fig.5.1). The effect of N was stronger on grain than on head weight/ plant (Table 5.6). In Kola Diba only, the lowest yields were observed in N_0 while the difference between the insecticide treatments was not significant. The yield increments between N_0 and the other treatments were between 63 and 69% (Table 5.6). In Chefa, though grain yields increased gradually with N dosage, the differences were not significant.

Table 5.4 Least square means (±SE) of percent larval parasitism at Chefa, eastern Amhara, at different levels of nitrogen fertilizer and insecticide application on maize and sorghum.

	Maize		Sorghum	
N fertilizer (kg ha^{-1})	Treated	Untreated	Treated	Untreated
N_0	0.0±0.0aA	2.0±1.0aA	0.0±0.0aA	0.8±0.5aA
N_1	0.0±0.0aB	5.6±2.4aA	0.0±0.0aA	0.2±0.1abA
N_2	0.0±0.0aB	6.9±2.6aA	0.0±0.0aA	1.3±0.9bA
N_3	0.6±0.5aB	7.4±2.8aA	1.3±1.0aA	3.8±1.6abA
F value	0.99	1.13	1.00	2.84
P value	0.3931	0.3375	0.3931	0.0383

Means within rows within a particular crop type followed by the same upper case letter and those means within a column within a particular treatment followed by the same lower case letter are not significantly different at P≤0.05 (SNK).

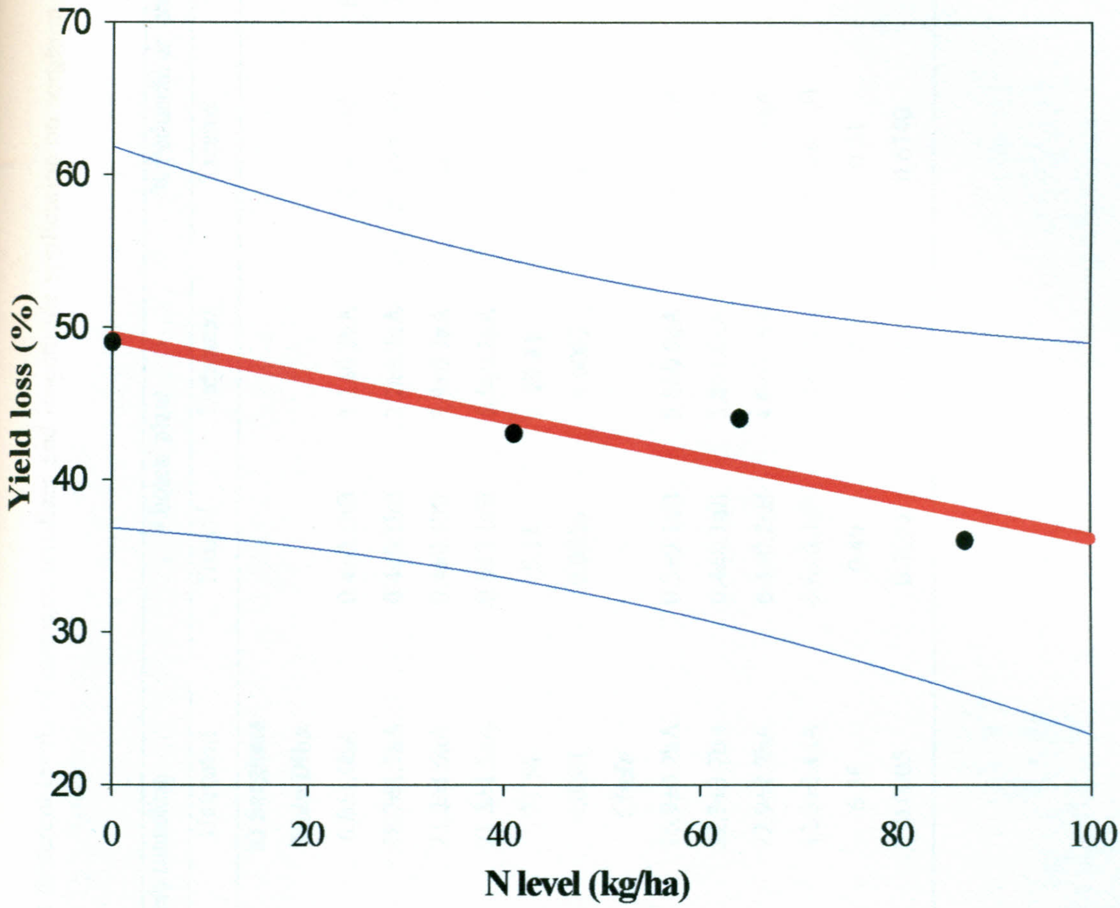


Fig. 5.1 The relationship between N fertilizer level and grain yield loss on sorghum at Kola Diba, western Amhara (red curve shows the trend of yield loss and the other two curves show the confidence interval).

Table 5.5 Least square means (±SE) of damage symptoms at different levels of nitrogen fertilizer and insecticide application on sorghum and maize in the Amhara state, Ethiopia.

N fertilizer	% Internode damage		% Stem tunneling		# holes/ plant		% Peduncle or cob damage*	
(kg ha^{-1})	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
				a) Sorghum				
				Kola Diba				
N_0	4.0±0.7abB	8.9±1.1bA	2.8±0.5bB	6.8±1.0bA	0.4±0.1bB	1.1±0.2bA	4.9±2.2bB	66.5±15.6aA
N_1	2.7±0.5bB	26.9±1.6aA	1.8±0.4bB	18.7±1.3aA	0.4±0.1bB	3.2±0.2aA	25.9±8.1abB	70.1±19.1aA
N_2	3.8±0.7abB	27.9±1.8aA	2.3±0.4bB	21.2±1.6aA	0.4±0.1bB	3.9±0.3aA	18.2±6.4abB	91.4±5.1aA
N_3	5.2±0.7aB	28.2±1.7aA	4.6±0.7aB	21.5±1.5aA	0.8±0.1aB	3.5±0.3aA	38.9±5.6aB	93.2±6.1aA
F value	2.30	27.97	5.20	21.54	5.14	23.81	5.64	1.16
P value	0.0757	<.0001	0.0014	<.0001	0.0016	<.0001	0.0120	0.3657
				Chefa				
N_0	2.2±1.0aB	31.6±3.9aA	3.0±1.1aB	26.9±3.2bA	0.3±0.1aB	5.0±0.9aA	1.9±1.6aB	9.4±3.0bA
N_1	4.4±1.3aB	41.9±4.9aA	4.2±1.1aB	32.3±3.7bA	0.4±0.1aB	5.8±1.0aA	0.3±0.3aB	19.8±4.2aA
N_2	3.2±1.2aB	27.7±2.9aA	2.7±1.0aB	22.9±2.2bA	0.4±0.2aB	4.0±0.7bA	1.4±1.3aA	7.3±3.0bA
N_3	4.8±2.0aB	41.1±3.8aA	2.9±1.4aB	42.3±3.4aA	0.6±0.3aB	7.6±0.8aA	0.5±0.4aB	17.3±4.1aA
F value	0.68	3.22	0.27	6.16	0.40	2.62	0.51	2.79
P value	0.5642	0.0245	0.8496	0.0005	0.7552	0.0520	0.6740	0.0423

b) Maize

				Kola Diba				
N_0	0.1±0.1aB	1.8±0.7aA	0.2±0.2aA	1.3±0.6abA	0.01±0.01aB	0.2±0.1bA	1.1±0.96aA	3.8±1.25aA
N_1	0.0±0.0aB	1.3±0.5aA	0.0±0.0aB	0.8±0.3abA	0.00±0.00aB	0.3±0.1bA	0.1±0.04bB	0.6±0.17bA
N_2	0.2±0.2aA	0.4±0.2bA	0.4±0.3aA	0.3±0.1bA	0.07±0.05aA	0.1±0.1bA	0.1±0.05bB	1.1±0.39bA
N_3	0.0±0.0aB	2.7±0.8aA	0.0±0.0aB	1.8±0.6aA	0.00±0.00aB	0.6±0.2aA	0.3±0.15bA	0.8±0.22bA
F value	1.38	3.46	0.95	3.24	1.55	4.54	2.97	8.76
P value	0.2483	0.0164	0.4169	0.0222	0.2022	0.0038	0.0309	<.0001
				Addis Zemen				
N_0	0.0±0.0aA	1.8±1.6aA	0.0±0.0aA	0.3±0.3aA	0.0±0.0aA	0.5±0.4aA	0.5±0.3aA	0.5±0.4aA
N_1	0.0±0.0aA	5.5±2.3aA	0.0±0.0aA	1.2±0.5aA	0.0±0.0aB	1.2±0.5aA	0.0±0.0bA	0.0±0.0bA
N_2	0.0±0.0aB	6.2±2.2aA	0.0±0.0aA	1.3±0.6aA	0.0±0.0aB	1.8±0.7aA	0.1±0.1A	0.2±0.1abA
N_3	0.4±0.4aA	5.0±2.0aA	0.1±0.1aA	0.5±0.3aA	0.2±0.1aA	0.8±0.4aA	0.0±0.0bA	0.2±0.1abA
F value	0.98	0.92	0.98	1.22	0.98	1.17	14.68	2.24
P value	0.4056	0.4360	0.4056	0.3069	0.4056	0.3263	<.0001	0.0824
				Chefa				
N_0	0.7±0.4aB	15.8±2.3aA	0.3±0.3aA	6.2±1.2aA	0.3±0.2aB	3.7±0.7aA	0.3±0.2aA	0.6±0.3aA
N_1	0.5±0.3aB	9.4±2.3aA	0.8±0.7aA	5.7±1.3aA	0.1±0.1aB	2.9±0.8aA	0.2±0.1aA	0.2±0.1aA
N_2	0.0±0.0aB	19.2±3.4aA	0.0±0.0aA	8.8±1.8aA	0.0±0.0aB	6.0±1.3aA	0.1±0.1aA	0.4±0.2aA
N_3	0.0±0.0aB	14.1±2.3aA	0.1±0.1aA	7.1±1.5aA	0.0±0.0aB	3.6±0.6aA	0.2±0.1aA	0.5±0.2aA
F value	1.85	2.28	0.71	0.87	2.28	2.32	0.32	0.59
P value	0.1398	0.0817	0.5493	0.4598	0.0816	0.0770	0.8087	0.6241

Means within rows within a particular damage variable followed by the same upper case letter and those means within a column within a particular location followed by the same lower case letter are not significantly different at P≤0.05 (SNK); * % peduncle damage for sorghum and % cob damage for maize.

Table 5.6 Least square means of sorghum head and grain weight at Kola Diba, and Chefa at different levels of nitrogen fertilizer and insecticide application, Amhara state, Ethiopia.

N fertilizer level	Head weight (g plant^{-1})		Head weight loss (%)	% Increment (head weight)		Grain yield (kg ha^{-1})		Grain weight loss (%)	% Increment (grain yield)	
	Treated	Untreated		Treated	Untreated	Treated	Untreated		Treated	Untreated
a) Western Amhara										
Kola Diba										
N_0	19.8cA	18.3bA	-	-	-	798.3bA	407.8bB	48.9	-	-
N_1	34.3bA	34.2aA	-	42.3	46.5	1975.6aA	1133.2aB	42.6	59.6	64.0
N_2	43.4aA	29.5aB	32.0	54.4	38.0	2158.2aA	1200.7aB	44.4	63.0	66.0
N_3	50.7aA	26.8abB	47.1	60.9	31.7	2456.5aA	1575.4aB	35.7	67.5	74.1
b) Eastern Amhara										
Chefa										
N_0	147.2aA	109.6aB	25.5	-	-	2225.7aA	1766.4aA	-	-	-
N_1	142.3aA	105.9aB	25.6	-	-	2684.3aA	2233.8aA	-	-	-
N_2	149.7aA	125.1aB	16.4	-	-	2703.9aA	2200.8aB	18.6	-	-
N_3	145.7aA	112.0aB	23.2	-	-	2728.9aA	2022.1aB	26.0	-	-

Means within rows within head weight or grain weight followed by the same upper case letter, and those means within a column within a particular location followed by the same lower case letter are not significantly different at $P \leq 0.05$ (SNK); - indicates no advantage by using insecticide or fertilizer on weight of cob or yield; * % yield increment was calculated by comparing N_0 with means N_0 -N_3.

On maize, the insecticide treatments had no significant effect on yields for most N treatments (Table 5.7). The exceptions were N_3 in Addis Zemen and Chefa with grain losses due to stemborers of 30.1 and 23.6%, respectively. In Kola Diba and Addis Zemen, yields increased with N dosage whereby the gains were greater in grain than in cob weight. N had no effect on maize yields in Chefa (Table 5.7). Apart from N_0, percent yield increment seemed to increase with N dosage from N_1 to N_3 at Addis Zemen and Kola Diba.

5.3.6 Relationships between pest and plant variables, leaf nitrogen content, nitrogen fertilizer level and borer populations

Regression analyses were conducted for western Amhara, where response to N fertilizer was noted. Multiple regression analyses on both maize and sorghum showed that both head and cob weight (Y) were positively related to N fertilizer (x_1), insecticide (x_2), and plant growth parameters (i.e., plant height, x_3, stem diameter, x_4, number of internodes, x_5), but negatively to the damage variables (i.e., internode damage, x_6, # holes/ plant, x_7, tunneling length, x_8), and borer density, x_9. It yielded the equation, $Y= -41.9 + 0.1x_1 + 3.2x_2 + 40.0x_3 + 62.2x_4 +0.8x_5 - 0.3x_6 - 7.0x_7 - 1.6x_8 -0.001x_9$, F=239.9, P<0001, r^2=0.62. For head weight (g/ plant) the equation was, $Y = -48.5 + 0.03x_1 + 10.12x_2 + 26.71x_3 + 1.93x_4 + 19.44x_5 - 0.69x_6 - 0.89x_7 - 0.78x_8 - 0.55x_9$, F=43.9, P<.0001, r^2=0.38.

On maize, percent parasitism (Y) was not affected by nitrogen fertilizer level (N) and borer density while on sorghum N (x_1) and insecticide treatment (x_2) were significant ($Y=1.33 + 0.58x_1 - 1.23x_2$; F=3.2, r^2=0.24, P=0.0237).

Simple regressions between percent total leaf nitrogen content and N fertilizer level, and between borer density and percent leaf N content, showed positive relationship on both crops. Leaf N to fertilizer level on maize gave Y=0.23x + 0.54, r^2=0.96, on sorghum, Y=0.1x + 1.12, r^2=0.96. Borer density to percent leaf N content on maize gave Y=0.24x-0.1, r^2=0.97, and on sorghum, Y=0.71x-0.1, r^2=0.64.

Table 5.7 Least square means of maize cob weight and grain weight at different levels of nitrogen fertilizer and insecticide application, at Kola Diba, Addis Zemen and Chefa, Amhara State, Ethiopia.

N fertilizer Level	Cob weight ($g\ plant^{-1}$)		% Cob weight loss	% Increment (cob weight)		Grain yield ($kg\ ha^{-1}$)		% Grain yield loss	% Increment (grain yield)	
	Treated	Untreated		Treated	Untreated	Treated	Untreated		Treated	Untreated
				a) Western Amhara						
				Kola Diba						
N_0	28.3cA	23.1dA	-	-	-	32.5cA	181.1bA	-	-	-
N_1	47.3bB	56.8cA	-	40.2	59.3	907.5bA	1144.1aA	-	98.4	84.2
N_2	104.2aA	97.6bA	-	72.8	76.3	2085.8abA	1651.1aA	-	98.4	89.0
N_3	105.9aA	108.3aA	-	73.3	78.7	2540.9aA	2152.4aA	-	98.7	91.6
				Addis Zemen						
N_0	101.4dA	103.4cA	-	-	-	872.8cA	859.7bA	-	-	-
N_1	114.0cA	105.9cB	12.4	11.1	-	3216.7bA	1773.5bA	-	72.9	51.5
N_2	142.0bB	178.3aA	-	28.6	42.0	5144.4aA	4388.1aA	-	83.0	80.4
N_3	161.6aB	186.3aA	-	37.3	44.5	5802.07aA	4057.2aB	30.1	85.0	78.8
				b) Eastern Amhara						
				Chefa						
N_0	156.9aA	134.1aA	-	-	-	1559.6aA	1569.7aA	-	-	-
N_1	144.0aA	123.1aA	-	-	-	1455.3aA	1273.3aA	-	-	-
N_2	155.8aA	149.8aA	-	-	-	1628.2aA	1435.3aA	-	-	-
N_3	156.0aA	135.5aA	-	-	-	1660.4aA	1269.1aB	23.6	-	-

Means within rows within cob weight or grain weight followed by the same upper case letter, and those means within a column within a particular location followed by the same lower case letter are not significantly different at $P \leq 0.05$ (SNK); - indicates no advantage by using insecticide or fertilizer on weight of cob or yield; * % yield increment was calculated by comparing N_0 with means N_0-N_3.

5.4 Discussion

The percent N content in leaves of sorghum and maize significantly increased with increasing N dosages. Similarly, Chau *et al.* (2005) reported increasing leaf N content with increasing fertilization level in ornamental plants. However, Jiang and Schulthess (2005) reported differences in plant N content between plants fertilized with N and those that were not fertilized. They did not report increasing N content with increasing fertilization. The lack of response to fertilizer inputs in eastern Amhara could be explained by better soil fertility status in Chefa trial site than western Amhara. Soil fertility is low in the Amhara state (Esilaba *et al.*, 2000; Getachew and Wondimu, 2005) and generally in Ethiopia (Tolessa *et al.*, 2001). However, the soils at Chefa trial site had higher percent N content, available phosphorus and % organic carbon compared to soils of all trial sites in western Amhara. Precipitation in eastern Amhara is low causing low runoff (erosion), nutrient leaching and low exploitation by cropping (since in some years drought situation prevents cropping and saves soil nutrients), contributing to better soil fertility status than in the west. In contrast to western Amhara, farmers in eastern Amhara grow cereals without fertilizer (Getachew Alemu, Sirinka Research Center, Ethiopia, pers. Comm.).

B. fusca was the major stemborer species in western while *C. partellus* in eastern Amhara. Western Amhara is generally higher, cooler and enjoys higher and relatively evenly distributed rainfall pattern compared to the sorghum and maize growing areas of eastern Amhara. A similar distribution of borer species was reported earlier in the same region (Emana *et al.*, 2001; Ferdu *et al.*, 2001; Melaku Wale, Bahir Dar, Ethiopia, unpub.). *R. niger* was found attacking sorghum plants mainly in eastern Amhara. Emana *et al.* (2001) also reported it on sorghum alone. Its importance, biology and ecology are not known and so far it has never been reported on other cereal crops.

In eastern Amhara, there was no response to N fertilizer application, and much of the discussion is based on the results in western Amhara.

Generally, borer population on sorghum tended to increase particularly on the insecticide free plots with increasing N fertilizer level in western Amhara. Densities were low on maize. Numerous studies showed the positive effects of N nutrients on borer incidence and survival in cereals (Archer *et al.*, 1987; Martin *et al.*, 1989; Setamou *et al.*, 1993, 1995; Moeser, 2003; Chabi-Olaye *et al.*, 2005a) and on aphids on wheat (Zhou and Carter, 1992). Singh and Singh (1969) suggested the mechanism for more borer density due to decrease in C/N ratio in the plant was as a result of N fertilizer application, where the addition of N fertilizer tilts the balance of the C/N ratio in the plant in favor of borer survival. Jiang and Schulthess (2005) suggested that greater N supply would increase protein production and decrease the carbohydrate content resulting in the formation of softer tissues that ease larval penetration.

In the present experiment, borer numbers increased with crop phenological stage, where, in sorghum, contrary to maize, borer numbers and damage continued far into the advanced stages of the crop, corroborating reports by Ogwaro (1983). Maize has a highly phasic growth pattern with distinct vegetative and reproductive phases and no tillering, while sorghum continues tillering at all times and also stem growth, unlike maize, occurs simultaneously with panicle development (Peacock and Wilson, 1984). Therefore, age of the plant influences the dynamics of nitrogen allocation in different parts of the plant and thereby survival of especially young borer larvae (Jiang and Schulthess, 2005). This could explain the higher density of borers for a long time in sorghum than in maize in the present experiment. Although the two crops were planted at the same time, maize matured a month earlier than sorghum and almost escaped the heaviest borer pressure that was observed on sorghum. Ferdu (1991) and Assefa (1982) reported the highest borer occurrence in southern Ethiopia at 4 to 6-week old maize plants compared to 9, 11 and 12-week old ones. This is in agreement with the present findings in western Amhara, where older maize plants are less attacked than younger plants.

Parasitism was low with means ranging from nil to 7.4% and tended to increase with N level, though not significantly, especially on the insecticide free plots on both maize and sorghum corroborating reports by Jiang and Schulthess (2005). They reported mean parasitism ranging from 5 to 12%, which was a bit higher than in the present work. In contrast, parasitism was high on long maturing traditional sorghum varieties (240-day varieties) grown by farmers in the same area (Melaku Wale, Bahir Dar, Ethiopia, unpub.).

On the untreated plots, damage parameters (tunneling, holes and internode damage) increased with N fertilizer level on sorghum especially in western Amhara corroborating results on maize by Setamou *et al.* (1995) and Chabi-Olaye *et al.* (2005a). In eastern Amhara, fertilizer levels did not have effect on damage possibly due to the already better soil fertility as shown by higher soil N content. Sorghum matured 1-month later than maize and was attacked more severely and for a long time than maize in western Amhara and damage was also increasing with crop phenology. Maize plants were more susceptible to borer attack at 4- and 6-week old than later growth stages of maize in southern Ethiopia (Ferdu, 1991), which was in agreement to the present results of lower damage at the advanced stages of maize plants. Head, cob and grain weight significantly higher on the fertilizer treated plots compared to plots without fertilizer at Kola Diba and Addis Zemen, but not at Chefa. From 16- to 47%

head weight and 18- to 49% grain weight loss was recorded on maize and sorghum, respectively. In other parts of Ethiopia, crop losses on maize or sorghum have been estimated from field surveys or field trials, though without different N levels as treatments, and they range from 15 to 100% (Assefa, 1989; Tadesse, 1989; Gashawbeza and Melaku, 1996; Emana, 1998b). In Africa, losses due to *B. fusca* vary with regions, i.e., 17 to 44% (Ndemah and Schulthess, 2002), up to 23.3% (Chabi-Olaye *et al.*, 2005a) both in Cameroon, and 25% (Usua, 1967) in Nigeria, which is in agreement with the results obtained from the current study.

Yield loss on sorghum tended to decrease with increase in nitrogen fertilizer at Kola Diba, where borer infestation and damage was high (from 49% at N_1 to 36% at N_3), but on maize there was no discernable trend due to low borer infestation. Several workers reported decreasing yield loss with increase in artificial or natural fertilizer (Setamou *et al.*, 1995; Chabi-Olaye *et al.*, 2005a; Mgoo, 2005). Ingram (1958) reported that when growth of sorghum is poor and the plants are dwarfed and thin-stemmed, damage by *C. partellus* can often cause 100% yield loss. However, this did not hold true in maize at the present study due to low borer infestation. Furthermore, there was no response to fertilizer at Chefa due to better soil nutrient status.

Yield increment on sorghum at Kola Diba due to fertilizer application was observed between N_0 and $N_{1\text{-}3}$, but not between N_1 through to N_3. Yield increment differences between N_1 through to N_3 were noted on maize at Kola Diba (99% on N_2 to 61% on N_3) and Addis Zemen (73% on N_2 to 41% on N_3).

Similarly, borer populations steadily increased with leaf nitrogen concentration corroborating results by Setamou *et al.* (1993) from a fertilizer trial, which gave a positive relationship between the survival of young larvae and N applied, and Chab-Olaye *et al.* (2005a), which reported similar relationship between larval survival and high leaf N contents of plants in the fallow and crop sequence treatments by legumes.

In general, multiple regressions showed positive relationship between yield (cob weight, head weight, and grain yield) and fertilizer, insecticide and plant growth parameters (plant height, stem diameter, internodes), but negative between yield and damage variables and borer populations. Similarly, in Benin, Setamou *et al.* (1995) and in Kenya (Songa *et al.*, 2001) reported that maize yield is determined by plant height, stem diameter and stem tunneling. Stem tunnelling is accepted to be a good indicator of the degree of plant damage and, thus, yield loss (Bosque-Perez and Mareck, 1991; Van den Berg *et al.*, 1991; Kalule *et al.*, 1994; Kalule *et al.*, 1997). In Cameroon, Ndemah and Schulthess (2002) reported negative relation between maize yield and percent tunnelled stem above the ear, and Chabi-Olaye *et al.* (2005a) between yield and tunnel, internodes bored and ear damage. However, on sorghum, Macfarlane (1990) reported that percentage internodes damage had more consistent negative relationship than tunneling to grain yield due to *B. fusca* in Nigeria.

The objective of the study was to assess the borer damage and yield loss as influenced by nitrogen fertilizer in the Amhara State of Ethiopia. The results showed that borers caused yield loss levels as high as half the potential implying the need for preventive or control action. The application of N fertilizer also increased yield significantly in western Amhara while progressively reducing the yield loss, especially on sorghum, with increase in N level. In conclusion, contrary to eastern Amhara, soil fertility is lower in western Amhara trial sites and maize and sorghum respond to fertilizer application, which increases yield, encourages borers and their damage but at the same time reducing the yield loss caused by borers, in conditions of significant borer presence. Cost-benefit analysis of the use of fertilizers, in relation to their role in borer management is subject for future investigation.

CHAPTER SIX

EFFECT OF CROPPING SYSTEMS ON STEMBORERS, THEIR NATURAL ENEMIES, AND DAMAGE ON MAIZE AND SORGHUM

6.1 Introduction

Although maize and sorghum are two of the most important crops in Ethiopia (Birhane, 1977; CSA, 2000) and in Africa at large (FAO, 2003), stemborers pose serious threat to the realization of their potential (Assefa, 1985; Assefa, 1989; Tadesse, 1989; Gashawbeza and Melaku, 1996; Emana, 1998; Emana, 2002).

To date, non-pesticide methods of pest control are preferred (CTA, 1997; Kfir *et al.*, 2002). Pest management tactics such as biological control agents, host plant resistance and habitat management are gaining momentum.

The traditional objective of agricultural research has been to enhance crop production in two dimensions: increasing the cultivated area and increasing yields per unit area per crop (Sanchez, 1976). Crop production can still be intensified in two additional dimensions: time and space. The goal of research is to increase food production in both dimensions (Listinger and Moody, 1976). Intercropping is the growing of two or more crops simultaneously on the same field (Andrews and Kassam, 1976; Nwanze, 1997). It also involves cropping patterns and crop density combinations (Nwanze, 1997). The effects of intercropping on arthropods are believed to be due to increased diversity in the agroecosystem, increased fertilization and crop growth, and non-host effects from the associated crop (Baliddawa, 1985). Populations of insect pest species are depressed under high species diversity (Baliddawa, 1985). Russell (1989) and Andow (1991) reviewed the enemies hypothesis regarding the effect of vegetational diversity on predatory insects and parasitoids; this hypothesis states that predators and parasites are more effective in complex intercropping systems than simple or sole crop environments. Thus, predators and parasites kill herbivores (insect pests) at higher rates in polycultures than monocultures. Russell (1989) further explained that the enemies hypothesis and the resource allocation hypothesis (which predicts that insects more easily find, stay in, and reproduce in monocultures of host plants than in polycultures) are complementary mechanisms.

Mixed cropping systems are widespread on subsistence farms in developing countries of the tropics (Francis *et al.*, 1976). It is estimated that 98% of cowpea (*Vigna* sp.), probably the most important legume in Africa, is grown in association with other crops (Arnon, 1972). A survey in Northern Nigeria by Norman (1974) reports 83% of the cropland was in mixed cropping. In Colombia 90% of the bean (*Phaseolus* sp.) crop is grown in association with maize (*Zea mays* L.), potatoes (*Solanum tuberosum* L.) and other crops while in Guatemala 73% of the bean production is from associated cropping, principally with maize (Francis *et al.*, 1976).

Habitat management and/or cultural practices stabilize the habitat maintaining indigenous natural enemies in the otherwise fragile ecosystem (Kfir *et al.*, 2002). Currently, attempts are being made universally to integrate non-pesticide options for the control of insect pests (Glen, 2000). The effect of cropping systems on stemborers and the introduced and native biological control agents must be assessed in order to guarantee their success (CTA, 1997; Nwanze, 1997). In Kenya, several plant species are identified which could serve as trap or repellent plants in push-pull strategy of stemborer management (Khan *et al.*, 2001). Khan *et al.*, (1997) reported the effectiveness of intercropping maize with non-host molasses grass. In doing so, the volatile agents produced by molasses grass repelled stemborers but attracted foraging

C. sesamiae (Khan *et al.*, 1997). Intercropping is widely practiced in the Amhara state, but its effect on stemborers and their natural enemies is virtually unknown.

Stemborer management research activities in Ethiopia have been going on in the Rift Valley area, central, eastern and southern parts of the country. This indicates that there exist serious gaps in stemborer research in the country. Some gaps are geographical, like the almost total absence of information from the Amhara State, apart from limited surveys carried out recently on the distribution of stemborers (Emana, 2002). Although the Amhara State is one of the first few major grain producing areas in the country and pest problems exist, there has not been any study on borers (Shegaw *et al.*, 1999; Melaku Wale, pers. obs.). The objective of the present experiment was to contribute to fill the gap and contribute further to food self-sufficiency in the state, and in the country as a whole. The present study tried to assess the effect of an indigenous multiple cropping system, i.e., intercropping different crops with maize and sorghum, against stemborers, as it applies to the Amhara state. The information obtained will serve as a springboard for future research and development efforts and contribute for the extension program, which is underway in the Amhara State of Ethiopia.

6.2 Materials and methods

6.2.1 Experimental sites

The study was conducted in the Amhara National Regional State (ANRS) at three different locations: Addis Zemen, Kola Diba, and Chefa. The fourth location was Zema but it escaped borer damage. Specific details of each location are given in the General Materials and Methods section.

At Kola Diba, western Amhara, maize trials were planted in mid June and harvested during the third week of November; at Addis Zemen there was one week delay in planting and harvest. The crop matured in five months. At Chefa trial site, eastern Amhara, both maize and sorghum were planted in mid July, just one month later than in the west, and harvested at about the same time as in the west, i.e., during the last week of November. At Chefa, both maize and sorghum required four months to mature. The area is characterized by shorter rainy season and crop varieties there need to mature earlier than in western Amhara.

6.2.2 Experimental set up

Western Amhara

Farmers in western Amhara State of Ethiopia traditionally intercrop maize, not sorghum, with Ethiopian mustard (*Brassica carinata* Braun) (Cruciferae), Irish potatoes (*Solanum tuberosum* L.) (Solanaceae) and faba bean (*Vicia faba* L.) (Leguminosae). In this study, maize was intercropped with these indigenous intercrops to determine their effect on stemborers and their natural enemies. The trial was arranged in a Randomised Complete Block Design (RCBD), replicated 4 times, with a row spacing of 0.75 m. Spacing between replicates (blocks) and plots were 3 m and 2 m, respectively. Therefore, treatments were maize + brassica/ mustard, maize + potatoes, maize + faba bean, maize + cowpea, and sole maize.

Cowpea (*Vigna unguiculata* (L.) Walp. (Leguminosae) is a new crop to the area and the newly released variety, *Bekur*, was used as one of the intercrops. The mustard variety, *Tul*, which grows well in areas of 2000-2600 m elevation, and 700-1000 mm of rainfall was planted. The faba bean variety, *CS 20 DK*, used in this study adapted to 2300-3000 m elevation and 700-1100 mm rainfall (ESE, 2001). The Irish potato variety *Tolcha* is grown in both highland and intermediate altitude areas (ENSIA, 1998). It requires sufficient moisture at the early stage of growth especially in the first 5-6 weeks. It thrives well on sandy and fertile soils with good seedbed and yields 20-50 tons/ha (ENSIA, 1998). The test crop was maize hybrid *BH 540* that is adapted to elevations of 1000-2000 m a.s.l., and a rainfall of 1000-1200 mm (ESE, 2001). It matures in 145 days, has a plant height of 230-260 cm; it tassels in 70 days and yields 5.0-6.5 tons/ha.

Potatoes were planted on alternate rows, with every other row planted with maize crop. That means half the area, which would normally be taken up by maize, was occupied by potatoes. The other intercrops were planted just between the normal maize rows. Fig. 6.1 shows some of the intercropping systems.

Eastern Amhara

Intercropping is common both on sorghum and maize in eastern Amhara. Experimental designs in eastern Amhara were the same as in western Amhara, excepting the types of intercrops used, and the difference in the agroecology. The intercrops selected were those that are suited to the farming system in the area. The farming system in eastern Amhara is different from that of western Amhara. Thus, the intercrop varieties used were, cowpea *Bekur*, sesame *Abasina*, haricot beans (*Phaseolus vulgaris* L.) *Wodo*, and sweet potatoes *Belela*. Maize variety *Katumani* and sorghum variety *Yeju* were used.

Fig. 6.1 Some of the field trials on cropping systems.

6.2.3 Sampling procedures

Sampling was carried out at different crop growth stages of the crop including vegetative, tasseling/grain filling, and harvest.

Destructive sampling was carried out, in which 10-20 plants per plot were randomly cut at ground level from the four outermost rows per plot, two rows on each side of the plot. At harvest up to 100 plants were sampled for destructive sampling and grain yield data. The plants were dissected to find all developmental stages of borers and natural enemies, which were counted and identified. The borers recovered were taken to the laboratory and reared on host diet for adult borer or parasitoid emergence. At the same time, plant height and diameter, number of leaves, internodes, entry and exit holes, damaged and undamaged internodes, and stem tunnelling were recorded per plant.

6.2.4 Statistical analysis

An analysis of variance (ANOVA) was conducted using the general linear model (SAS, 1999-2000) to assess the effects of various intercropping systems on borer density, natural enemies, borer damage, yield and its components, and plant growth variables. Data analysis focused on data collected at the vegetative, tasseling, grain filling and harvest stages. Borer data were more complete and higher at these stages. Stepwise regressions analyses were performed between cob and head weight and plant growth parameters, damage variables and borer density. For assessment of the effect of borers on plant growth variables at harvest, an insect measure namely borer-days, defined as the mean number of borers observed on consecutive sampling dates multiplied by the days between samples, and then summed over the whole sampling period was used (Setamou *et al.*, 1995). This measure was chosen in addition to borer numbers because it takes into consideration borer density as well as duration of infestation (Schulthess *et al.*, 1991). Simple linear regression analysis was performed between percent parasitism and borer density across treatments.

6.3 Results

In 2003 cropping season, the maize intercropping trial planted at Zema matured early and successfully escaped borer damage. By the time the pest started its devastation, the maize plants were already at maturity stage.

6.3.1 Effect of intercrops on stemborer density

Western Amhara

B. fusca was the major borer species in western Amhara. Borer density significantly varied between intercrops at the vegetative stage in Addis Zemen and at harvest at Kola Diba (Table 6.1a). Plots intercropped with mustard had lower borer density, though not always significantly different from those with other intercrops. This situation was more obvious in terms of borer-days than the mere borer density (Table 6.1a). Generally, density across the intercrops was significantly higher at the vegetative stage at Addis Zemen, but tended to be higher until grain filling at Kola Diba, and declined at harvest at both locations (Table 6.1a).

Eastern Amhara

The major borer species was *C. partellus* and intercrops of the area had no impact on borer density (Table 6.1b). The density was lower at harvest stage than in earlier growth stages of maize but not on sorghum.

Table 6.1 The effect of indigenous intercrops on *B. fusca* and *C. partellus* (least square mean± SE) density per plant on maize and sorghum in the Amhara state, Ethiopia.

a) Cool-humid ecozone (*B. fusca*)

Intercrops	Addis Zemen				Kola Diba			
	Borer density			Borer-days	Borer density			Borer-days
	Vegetative	Grain filling	Harvest		Vegetative	Grain filling	Harvest	
Potatoes	0.20±0.22bA	0.06±0.05aA	0.10±0.04aA	5.5a	0.21±0.13aA	0.40±0.13aA	0.11±0.04aA	12.9
Mustard	0.05±0.24bA	0.00±0.05aA	0.03±0.03aA	1.1b	0.14±0.13aAB	0.14±0.13aA	0.10±0.04bB	8.0
Faba bean	1.87±0.28aA	0.00±0.05aB	0.00±0.04aB	21.8a	0.40±0.14aA	0.25±0.13aA	0.21±0.05aA	15.0
Cowpea	0.80±0.24bA	0.11±0.04aB	0.00±0.04aB	14.8a	0.26±0.14aAB	0.45±0.13aA	0.12±0.05aB	16.1
Maize sole	1.00±0.22abA	0.01±0.04aB	0.07±0.04aB	15.8a	0.50±0.14aA	0.32±0.14aA	0.27±0.05aA	17.6
F value	7.74	1.27	1.67	4.10	1.17	0.84	2.47	0.87
P value	<.0001	0.2905	0.1555	0.0498	0.3271	0.5013	0.0433	0.5041

Means of borer density within a column followed by the same lower case letter(s) and those within a row within Addis Zemen or Kola Diba followed by the same upper case letter(s) are not significantly different at P=0.05 (SNK).

b) Semi-arid ecozone (*C. partellus*)

	Maize			Sorghum		
	Borer density		Borer-days	Borer density		Borer days
Intercrops	Tasseling	Harvest		Heading	Harvest	
Sweet potatoes	2.67±0.34aA	0.25±0.14aB	39.0	3.33±0.51aA	4.28±2.39aA	114.4
Sesame	2.38±0.34aA	0.25±0.10aB	39.4	2.23±0.51aA	2.94±0.39aA	82.9
Haricot beans	1.67±0.34aA	0.20±0.10aB	28.0	1.90±0.51aA	3.15±0.36aA	75.8
Cowpeas	2.10±0.34aA	0.40±0.10aB	37.1	3.48±0.51aA	3.00±0.36aA	97.1
Sole maize	2.58±0.34aA	0.20±0.10aB	42.0	2.75±0.51aA	3.48±0.36aA	93.4
F value	1.02	0.70	0.41	1.75	1.13	1.43
P value	0.3995	0.5950	0.7996	0.1406	0.3451	0.2710

Means of borer density within a column followed by the same lower case letter(s) and those within a row within maize or sorghum followed by the same upper case letter(s) are not significantly different at P=0.05 (SNK).

6.3.2 Effect of intercrops on larval parasitism of *C. partellus* by *C. flavipes*

In eastern Amhara (Chefa), *C. flavipes* was observed parasitizing *C. partellus* larvae. However, the rate of parasitism was not as high as that on long maturing varieties in farmers' fields nearby. Intercrops varied significantly in percent parasitism but not in cocoon mass density per plant on both maize and sorghum; a maximum of 20% parasitism was recorded on plots intercropped with sweet potato (Table 6.2). Percent parasitism was higher on maize than that on sorghum. In western Amhara, the rate of parasitism was little, where only *Dolichogenidea fuscivora* Walker was found on two plants at Addis Zemen trial site. Simple regression analysis of percent parasitism against borer density showed no significant relationship, $y=13.5x-24.2$, $F=2.6$, $p=0.21$, $r^2=0.46$ for maize and $y=-0.2x+1.1$, $F=0.32$, $P=031$, $r^2=0.10$ for sorghum.

Table 6.2 Effect of indigenous intercrops on cocoon mass density and percent larval parasitism by *C. flavipes* (least square mean±SE) on maize and sorghum in eastern Amhara.

	% Larval parasitism		Cocoon masses/ plant	
	Maize	Sorghum	Maize	Sorghum
Sweet potatoes	20.00±4.76aA	0.56±1.02aB	0.35±0.11aA	0.10±0.04aA
Sesame	7.50±3.36abA	0.71±0.77aB	0.13±0.08aA	0.03±0.03aA
Haricot beans	0.00±3.36bA	0.50±0.72aA	0.23±0.08aA	0.03±0.03aB
Cowpeas	2.50±3.36bA	0.00±0.72aB	0.08±0.08aA	0.00±0.03aA
Sole	2.50±3.36bA	1.25±0.72aA	0.23±0.08aA	0.03±0.03aA
F value	3.45	0.39	1.25	1.22
P value	0.0096±	0.8191	0.2933	0.3050

Means within a column followed by the same lower case letter, and those within a row and within % larval parasitism or cocoons masses/plant followed by the same upper case letters, are not significantly different from each other at P≤0.05 (SNK).

6.3.3 Effect of intercrops on borer damage variables

In Addis Zemen, generally, percent stem tunneling and number of holes were higher at the vegetative stage, and in Kola Diba at grain filling stage. In Addis Zemen, differences in damage were significant among intercrops more at the vegetative stage than at later stages, where mustard had the most frequent reduction (Table 6.3). This pattern did not clearly happen at Kola Diba, where tunneling and cob damage were significantly different among intercrops at harvest, and % internode damage at the vegetative stage (Table 6.3). The lowest cob damage was observed on mustard plots in both locations.

In Chefa, percent stem tunneling and number of holes were significantly higher at harvest than at earlier growth stages (Table 6.4). Plots intercropped with sweet potatoes had significantly higher percent tunneling and the number of holes than the other intercrops. Cob damage was significantly different among intercrops, the highest being on sweet potatoes (Table 6.4).

6.3.4 Effect of intercrops on yield and its components

In Addis Zemen and Kola Diba, cob weight was significantly higher on plots intercropped with potatoes, and generally it was lower in sole maize (Table 6.5a). Generally, cob weight was often higher in Kola Diba than in Addis Zemen. It ranged from 29 g/plant on sole maize to 83g/ plant on plots intercropped with potatoes. There was no significant difference among intercrops in grain yield at both locations. However, sole crop in Addis Zemen yielded significantly less grain than the intercrop. Grain yields, though not significant, were higher in Kola Diba than Addis Zemen and it ranged from 1025 kg/ ha on sole maize plots to 3446 kg/ ha on plots intercropped with potatoes (Table 6.5a). In most cases, the yields tended to be higher on intercropped plots than sole plots with an increment as high as 100% (comparing sole maize plots with plots intercropped with cowpea). Sole maize seemed to have more cob damage than the intercrop maize. At Chefa, yields were higher on sorghum than on maize, especially on the sole plots and those intercropped with sesame (Table 6.5b).

Table 6.3 Effect of indigenous intercrops on borer damage variables (least square mean±SE) on maize in western Amhara, Ethiopia.

Intercrops	Addis Zemen			Kola Diba		
	Vegetative	Grain filling	Harvest	Vegetative	Grain filling	Harvest
			% Tunnelling			
Potatoes	1.66±0.98bA	0.50±0.38aAB	0.15±0.38aB	0.54±0.33aB	11.84±3.24aA	2.64±0.64abB
Mustard	0.43±1.10bA	0.17±0.40aA	0.22±0.35aA	0.13±0.33aB	10.79±3.32aA	2.30±0.64abB
Faba bean	6.29±1.27aA	0.00±0.38aB	0.36±0.38aB	0.67±0.34aB	11.92±3.32aA	1.48±0.72bB
Cowpea	2.06±1.10abA	1.11±0.36aA	0.40±0.38aA	1.13±0.35aB	9.12±3.32aA	1.86±0.73abB
Sole	3.89±1.10abA	0.14±0.36aA	1.23±0.38aA	0.78±0.34aA	8.49±3.41aA	4.46±0.75aA
F value	3.71	1.47	1.31	1.16	0.22	2.42
P value	0.0075	0.2191	0.2657	0.3303	0.9270	0.0470
			Holes/ plant			
Potatoes	1.16±0.65abA	0.50±0.38aAB	0.03±0.09aB	0.36±0.25aB	4.10±0.89aA	0.76±0.14aB
Mustard	0.25±0.73bA	0.13±0.40aA	0.11±0.08aA	0.05±0.24aB	3.80±0.92aA	0.57±0.14aB
Faba bean	3.80±0.84aA	0.00±0.38aB	0.10±0.09aB	0.70±0.25aB	3.60±0.92aA	0.52±0.15aB
Cowpea	2.15±0.73abA	1.00±0.36aAB	0.10±0.09aB	0.89±0.26aB	3.55±0.92aA	0.54±0.16aB
Sole	2.80±0.73abA	0.11±0.36aB	0.23±0.09aB	0.33±0.25aB	2.26±0.94aA	0.78±0.16aB
F value	3.27	1.24	0.71	1.77	0.57	0.68
P value	0.0140	0.3020	0.5820	0.1355	0.6824	0.6077

Table 6.3 Continued…

Intercrops	Addis Zemen			Kola Diba		
	Vegetative	Grain filling	Harvest	Vegetative	Grain filling	Harvest
			% Internode damage			
Potatoes	5.69±2.65abA	-	0.23±0.44aB	3.67±2.23aA	-	4.67±0.76aA
Mustard	0.62±2.96bA	-	0.68±0.40aA	0.33±2.21bA	-	3.11±0.75aA
Faba bean	15.43±3.41aA	-	0.33±0.44aB	6.92±2.29aA	-	2.22±0.85aB
Cowpea	8.26±2.96abA	-	0.47±0.43aB	7.28±2.35aA	-	2.66±0.86aB
Sole	9.66±2.96abA	-	1.19±0.43aB	5.31±0.89aA	-	5.31±0.89aA
F value	2.97	-	0.78	1.56	-	2.49
P value	0.0235	-	0.5399	0.1869	-	0.0419
			% Cob damage			
Potatoes	-	-	0.50±0.36aB	-	-	3.56±0.98bA
Mustard	-	-	0.15±0.35aA	-	-	1.10±0.97bA
Faba bean	-	-	0.28±0.38aB	-	-	2.40±1.10bA
Cowpea	-	-	0.21±0.36aA	-	-	2.41±1.10bA
Sole	-	-	1.28±0.36aB	-	-	12.17±1.10aA
F value	-	-	1.70	-	-	17.12
P value	-	-	0.1481	-	-	<.0001

Means within a column within each individual damage symptom followed by the same lower case letter, and those within a row and within a particular location followed by the same upper case letters, are not significantly different from each other at P≤0.05 (SNK).

Table 6.4 Effect of indigenous intercrops on borer damage variables (least square mean±SE) on maize and sorghum in Chefa, eastern Amhara, Ethiopia.

	Maize		Sorghum	
	Tasseling stage	Harvest	Heading stage	Harvest
	% Stem tunneling			
Sweet potatoes	0.77±00.16aB	4.28±2.39aA	1.53±0.31aB	49.22±5.00aA
Sesame	0.00±00.17bB	8.83±1.69aA	0.00±0.31bB	46.19±3.80aA
Haricot beans	0.10±00.17bB	9.14±1.69aA	0.00±0.31bB	33.65±3.55aA
Cowpeas	0.20±00.17bB	7.26±1.69aA	0.17±0.31bB	43.48±3.55aA
Sole	0.35±00.17bB	5.69±1.69aA	0.12±0.31bB	43.09±3.55aA
F value	3.35	1.13	4.62	2.26
P value	0.0111	0.3451	0.0014	0.0646
	# Holes/ plant			
Sweet potatoes	0.39±0.27aB	3.75±0.94aA	0.75±0.18aB	7.25±1.07aA
Sesame	0.38±0.28aB	3.65±0.94aA	0.05±0.18bB	5.06±0.81aA
Haricot beans	0.46±0.28aB	2.90±0.66aA	0.00±0.18bB	6.90±0.75aA
Cowpeas	0.30±0.28aB	2.48±0.66aA	0.08±0.18abB	5.33±0.75aA
Sole	0.53±0.28aA	1.45±0.66aA	0.10±0.18abB	6.58±0.75aA
F value	0.10	1.77	3.12	1.35
P value	0.9835	0.1378	0.0161	0.2525

Table 6.4 Continued ...

Inter crops	Maize		Sorghum	
	Tasseling stage	Harvest	Heading stage	Harvest
		% Internode damage*		
Sweet potatoes	-	11.57±3.26a	-	60.04±7.95a
Sesame	-	13.82±2.31a	-	51.67±5.92a
Haricot beans	-	14.27±2.31a	-	39.57±5.62a
Cowpeas	-	10.71±2.31a	-	44.53±4.93a
Sole	-	6.72±2.31a	-	51.63±4.87a
F value	-	1.71	-	1.49
P value	-	0.1490	-	0.2076
		% Cob damage/ chaffyness*		
Sweet potatoes	-	0.05±0.34a	-	31.56±3.81a
Sesame	-	0.20±0.24a	-	9.69±2.88b
Haricot beans	-	0.58±0.24a	-	7.45±2.69b
Cowpeas	-	0.13±0.24a	-	11.25±2.69b
Sole	-	0.43±0.24a	-	9.00±2.69b
F value	-	0.70	-	7.75
P value	-	0.5899	-	<.0001

* These were recorded at harvest only; means within a column within each individual damage symptom followed by the same lower case letter, and those within a row and within a particular location followed by the same upper case letter(s), are not significantly different from each other at P≤0.05 (SNK).

Table 6.5 Effect of intercrops on grain yield (kg ha^{-1}) and cob weight (g/ plant) (least square means±SE) of maize and sorghum in the Amhara State, Ethiopia.

a) Western Amhara

	Cob weight (g/ plant)		**Grain yield (kg/ ha)**	
	Addis Zemen	Kola Diba	Addis Zemen	Kola Diba
Potatoes	62.73±6.60aB	83.05±4.38aA	1470.83±453.19aA	3446.32±480.48aA
Mustard	44.46±6.43abB	67.36±4.33abA	1400.97±453.19aA	2261.25±480.48aA
Faba bean	53.26±6.93abA	45.73±4.78cA	1613.26±453.19aA	2447.78±480.48aA
Cowpea	40.34±6.66abA	56.74±4.93bcA	2168.82±453.19aA	2600.32±480.48aA
Sole	28.93±6.66bB	44.52±4.84cA	1015.42±453.19ab	2130.63±480.48aA
F value	3.72	12.49	0.85	1.16
P value	0.0054	<.0001	0.5144	0.3669

b) Eastern Amhara

	Grain yield (kg/ha)	
	Maize	**Sorghum**
Sweet potatoes	1427.60±161.45a	1910.97±188.88a
Sesame	1707.71±161.45a	2377.29±188.88a
Haricot beans	1698.91±161.45a	1758.39±188.88a
Cowpeas	1727.95±161.45a	2029.92±188.89a
Sole	1468.89±161.45a	2444.28±188.88a
F value	0.81	2.47
P value	0.5379	0.0893

Means within a column within cob weight (g/ plant) or grain weight (kg/ha) followed by the same lower case letter, and those within a row and within cob weight (g/ plant) or grain weight (kg/ha) followed by the same upper case letters, are not significantly different from each other at P≤0.05 (SNK).

6.3.5 Relationship between plant growth, damage, borer density and yield

In western Amhara, cob weight was positively related to plant height and stem diameter and negatively to both damage variables and borer density (Table 6.6a). In situations of low infestation, it was not possible to find negative relation between cob yield and cob damage (Table 6.6a). In eastern Amhara, the pattern was more or less the same, but due to lower infestation, some irregularities occurred in which tunneling and internode damage showed positive relation to cob/ head weight (Table 6.6b).

Table 6.6 Stepwise regression analysis of cob weight of maize with plant growth parameters, damage variables and borer density in western Amhara, Ethiopia.

a) Western Amhara

	b	F	P
		Across location	
Y cob weight (g/ plant)			
X_1 Plant height	38.58	118.87	<.0001
X_2 Stem diameter	61.03	1107.93	<.0001
X_3 % stem tunneling	-0.52	10.07	0.0015
X_4 % cob damage	-0.20	4.39	0.0363
Intercept=-45.80, r^2=0.50, N=1601			
		Addis Zemen	
Y cob weight (g/ plant)			
X_1 Plant height	34.78	34.49	<.0001
X_2 Stem diameter	60.78	291.54	<.0001
X_3 % cob damage	1.18	8.80	0.0032
Intercept=-48.63, r^2=0.42, N=536			
		Kola Diba	
Y cob weight (g/ plant)			
X_1 Plant height	49.69	123.70	<.0001
X_2 Stem diameter	57.50	705.53	<.0001
X_3 # holes/ plant	-1.82	7.15	0.0076
X_4 % cob damage	-0.27	8.30	0.0040
X_5 Borer density/ plant	-5.58	5.52	0.0190
Intercept=-51.65, r^2=0.55, N=1064			

b values are partial regression coefficients.

b) Eastern Amhara

	b	F	P
		Maize	
Y cob weight (g/ plant)			
X_1 Plant height	0.24	9.45	0.023
X_2 # internodes/ plant	17.15	126.89	<.0001
X_3 % stem tunneling	1.20	14.01	0.0002
X_4 Borer density/ plant	-10.50	42.99	<.0001
Intercept=-120.31, r^2=0.61, N=326			
		Sorghum	
Y head weight (g/ plant)			
X_1 Plant height	0.91	92.80	<.0001
X_2 Stem diameter	10.04	6.14	0.0137
X_3 # internodes/ plant	11.27	46.25	<.0001
X_4 % damaged internodes	0.17	5.74	0.0172
X_5 % cob damage	-0.50	16.13	<.0001
X_6 % stem tunneling	0.52	26.24	<.0001
X_7 Borer density/ plant	-1.26	4.62	0.0325
Intercept=-168.86, r^2=0.77, N=308			

b values are partial regression coefficients.

6.4 Discussion

In western Amhara, differences in borer densities among intercrops were higher during the vegetative stage than during the grain filling and harvest stages corroborating reports by Chabi-Olaye *et al.* in Cameroon (2005b). The temporal fluctuation pattern of borers on intercrops more or less followed that of the monocrop, in which borer density declined at harvest as compared to the vegetative, tasseling and grain filling stages. Setamou *et al.* (1995) described the nature of borer reduction at the advanced stages of the plants, when many of the borers become adults and fly away or get killed by natural enemies. Chabi-Olaye *et al.* (2005b) also concluded that larval numbers at harvest are not reliable indicators of the extent of infestation as most borers have reached adulthood. This situation was further confirmed in other field experiments carried out alongside the present study (Chapters 4 and 6.).

In eastern Amhara, although borer densities varied between maize growth stages, it did not do so between intercrops mainly because of lower infestation level during the main rainy season on such short season varieties of maize and sorghum. In western Amhara, plots intercropped with mustard had lower borer population than plots with other intercrops and sole maize. Findings reported on studies on the effect of intercrops on borers vary with location and crop combinations. For example, intercropping increased the level of stemborers in maize, was low in pure maize stands, and had no effect on sorghum in Mbita, Kenya (Ogwaro, 1983). According to Chabi-Olaye *et al.* (2005b) all the intercropped plots (i.e., cassava, cowpea and soy beans) had lower borer density than the monocrop, while in the present study, the lowest borer density was observed on mustard plots compared to other intercrops and the monocrop. Similarly, Schulthess *et al.* (2004) showed that the number of *S. calamistis* and *B. fusca* egg batches were consistently lower on the intercropped maize than on the monocrop. The intercrop mustard grew tall between maize plants and forced maize plants to grow high too in order to compete for sunlight. The most obvious phenomenon observed during the study was that mustard is leafy at its early growth stages and has numerous branches after flowering. The branches spread out in all directions impeding flying moths alighting on maize plants. Mustard successfully deterred them and showed the lowest borer numbers, via reduced oviposition. Schulthess *et al.* (2004) concluded that the presence of non-host plants reduced host-searching ability of ovipositing female moths. *B. fusca* larvae tend to migrate to neighbouring plants (van Rensburg *et al.*, 1988a), where migration related mortality of young larvae can be high in mixed cropping systems due to failure to find a suitable host (Chabi-Olaye *et al.*, 2005b). Many intercropping studies did not seek to find out the underlying mechanism behind the effect of intercropping on pest dynamics. Intercropping cowpea in maize, pest incidence was substantially reduced via two mechanisms: 30% of the borer eggs were laid on cowpea directly, while hatching larvae on cowpea had to migrate to neighbouring maize plants, the number of larvae reaching the maize plants decreased with distance (Ampong-Nyarko *et al.*, 1994). Similarly, Listinger and Moody (1976) reported that within crop mixtures, non-host crops for a pest might physically interfere with the pest's ability to find a host or interfere biologically by emitting chemicals that adversely affect pests, thereby protecting host plants. Strong smelling plants such as garlic, onion, coriander and tomatoes can prevent pest buildup (Listinger and Moody, 1976). Generally, plant species differ in attractiveness and suitability as hosts of arthropods, pathogens and nematodes; crops such as cassava (*Manihot esculenta* Crantz.) have few recorded pests while others, notably solanaceous crops, have large pest complexes, which are greater in the tropics than in temperate regions (Listinger and Moody, 1976).

Ethiopian mustard contains high levels of long chain monounsaturated fatty acids mainly erucic acid, which is beneficial more for the polymer industry than food oil (Tsige *et al.*, 2004). There are also several other fatty acids in Ethiopian mustard (Tsige *et al.*, 2004), whose effect on borers is not known and whether these compounds occur at the vegetative stage of the crop. Furthermore, differences in pest population in crops can be due to initial difference in the number of arrivals (Southwood and Way, 1970; Adesiyun, 1979) or to different rates of multiplication in the crop as well as mortality rate (Way and Heathcote, 1966).

Natural enemies are believed to account for more than half of the pest reduction in a weed-diversity system and only less than a third in crop-crop diversity system (Baliddawa, 1985). Thus, in annual crop combinations, like the present one, the role of natural enemies as a pest regulating factor should be low, which leads us to attribute the mechanism to other reasons such as obstruction of searching ability, etc. Russell (1989) and Andow (1991) reviewed the enemies hypothesis regarding the effect of vegetational diversity on predatory insects and parasitoids; this hypothesis states that predators and parasites are more effective in complex (intercropping) than simple (sole crop) environments. Thus, predators and parasites are more efficient in polycultures than monocultures. Furthermore, which kinds of polycultures do encourage natural enemies more? Weedy fields than crop-crop combinations encourage natural enemies more (Baliddawa, 1985). Russell (1989) further explained the enemies hypothesis and the resource allocation hypothesis, a hypothesis which predicts that specialized insects more easily find, stay in, and reproduce in monocultures of host plants than in polycultures, are complementary mechanisms. Simply put, monocultures encourage and discourage pests and natural enemies, respectively. In western Amhara, intercropping mustard with maize is a common practice (Aleligne and Regasa, 1992). Mustard is a valuable cash crop for farmers for they supply it to edible oil mills, and during the vegetative stage it provides farmers with much needed vegetable material rich in nutrients, and at a time when farmers face dwindling food reserves, The almost ubiquitous growing of mustard with maize might be one of the reasons why stemborers are negligible in three of the four zones in the region (Melaku Wale, in press). Although farmers do not use mustard in eastern Amhara, it might be assessed in short season (early maturing) varieties of maize and sorghum for later introduction to the region, since it is difficult to use it with the tall, long maturing sorghum varieties that dominate eastern Amhara.

Most intercropping studies carried out in eastern Africa for the last two decades concluded that cowpeas reduced stemborer incidence on maize and sorghum (Oloo and Ogeda, 1990; Ampong-Nyarko *et al.*, 1994; Scovgard and Pats, 1996; Pats *et al.*, 1997), which was not the case in the present study. In western Amhara, cowpeas generally did not perform well in the relatively colder weather and leaf beetles severely damaged the leaves. Many farmers grow maize and sorghum in mixture in many areas of the Amhara state, which was not fully covered during the current study. Such association is reported to cause heavy infestation of borers on maize but did not affect sorghum on the shores of Lake Victoria, Kenya (Ogwaro, 1983).

In western Amhara, no significant borer parasitism was observed, whereas, in eastern Amhara, though borer incidence and parasitism were generally low; mean percent parasitism was higher on maize plots intercropped with sweet potatoes. In other parts of Ethiopia, Emana (2002) reported higher percent parasitism on maize and sorghum plants intercropped with haricot bean (*Phaseolus vulgaris*) but not on sesame. In Kenya, molasses grass was reported to increase parasitism of stemborers by attracting parasitoids (Khan *et al.*, 2001; Gohole *et al.*, 2003). However, subsequent close-range studies showed that molasses grass did not deter the foraging behaviour of *C. sesamiae* and *Dentichasmias busseolae* (Gohole *et al.*, 2005). Responses to individual intercrops may vary with specific locations, type of intercrops and planting patterns. *C. flavipes* parasitism on *C. partellus* seemed to be higher on maize than on sorghum corroborating earlier reports by Jiang and Schulthess (2005) and Setamou *et al.* (2005). Jiang and Schulthess (2005) reported that *C. partellus* mortality and parasitism by *C. flavipes* was higher on maize than on sorghum. Simple regression analysis of percent parasitism with borer density showed no relationship due to low level of parasitism on these early maturing maize and sorghum varieties.

All the above statements on borers are applicable to damage variables. Damages happened to be significantly higher at the vegetative stage and less on plots intercropped with mustard, in exactly the same way as borer numbers. In Uganda, Kalule *et al.* (1997) reported that *C. partellus* and *B. fusca* caused higher damage before anthesis, i.e, at the vegetative stage. Similarly, Chabi-Olaye *et al.* (2005b) concluded that borer damage was directly proportional to the number of the attacking larvae, indicating direct relationship between borer density and damage. The specific situation observed in the present experiment was the decline in damage levels at harvest compared with earlier stages. This may be due to increasing plant height with declining borer will cause low percent damage at later growth stages (F. Schulthess, Nairobi, Kenya, pers. comm..). In western Amhara, cob weight and grain yield were higher on plots intercropped with potatoes probably because of the better aerial space which maize plants enjoyed when intercropped with potatoes. Despite the heavy foliage, potatoes do not grow high up to compete for sunlight and space with the maize plants. Potatoes grow and mature during the wet months leaving the space for the maize plants the rest of the season. In most cases, yields tended to be higher on the intercropped plots than on sole maize corroborating results by Chabi-Olaye *et al.* (2005b) and Schulthess *et al.* (2004). Yields in eastern Amhara were not significantly different between intercrops due to better soil fertility and lower borer incidence during the main season. Unlike reports in other countries like Kenya (Ogwaro, 1983), sorghum gave higher yield than maize; since sorghum is more drought resistant than maize, it can do well in drought-prone eastern Amhara region.

Stepwise regressions showed a variable association between yield and damage, plant growth variables, and borer numbers. However, in western Amhara, across location analysis of yield to damage, plant growth variables, and borer numbers gave positive relationship with plant growth, but negative with tunneling. This was corroborated by various authors on African borer species (Ogwaro, 1983; Bosque-Perez and Mareck, 1991; Gounou *et al.*, 1994; Setamou *et al.*, 1995; Ndemah *et al.*, 2000; Chabi-Olaye *et al.*, 2005b). Although the present results show lower borer incidence by intercropping maize with mustard, earlier agronomy studies in the same area indicate that faba bean had higher land equivalent ratio (LER), with a maximum LER record of 2.0 (Minale *et al.*, 2001). Apart from the mere yield increment, the growing of a mixture of faba beans and maize has several benefits including improved soil fertility, and protein supplement in the diet of the rural and urban poor in the Amhara State as well as the country with a population of 72 million. According to Bulson *et al.* (1990), cereals grown together with field beans can provide yield benefits compared to either crop grown alone. The presence of beans can also enhance predatory and parasitic insects in the cereal crop (Wratten and Powell, 1991). Agronomic studies in western Amhara State indicate a LER value of 1.23 for mustard (Tilahun Tadesse *et al.*, unpub.), which is one of the major cash crops for farmers in the Amhara State and an important raw material for edible oil mills nationwide. Furthermore, earlier agronomic studies showed that the economic analysis of mustard intercropping with maize were declared unprofitable (Tilahun Tadesse *et al.*, unpub.) and of faba bean profitable (Minale *et al.*, unpub.) compared with the sole maize planting. The present findings showed considerable reduction in borer damage levels by intercropping mustard in maize, as a result of reduced *B. fusca* infestation. However, in previous studies (Tilahun Tadesse *et al.*, unpub.; Minale *et al.*, unpub), the land equivalent ratio was favouring faba bean, which also plays a role in soil fertility improvement. The economic gain from the use of intercrops depends on the balance between a lowered cost of the control of stemborers and the increased cost of maintaining an intercropped field, along with any decrease in yield of the main crop from greater plant competition. Net benefit can be increased if the intercrop favourably changes the balance between income and costs (Kfir *et al.*, 2002). Economic data assessing the financial returns as well as the biological effects are therefore most useful in making decisions on the use of intercrops and trap plants for stemborer control. Future thrust must focus on the remaining crop combinations on more representative hotspot areas, such as Kola Diba on sorghum on well-drained red soils, mechanism of intercrops in borer reduction, testing mustard in eastern Amhara, and economic analysis of intercrops.

CHAPTER SEVEN

EFFECT OF PLANTING TIME ON STEMBORERS, THEIR NATURAL ENEMIES AND DAMAGE LEVELS IN SORGHUM IN WESTERN AMHARA

7.1 Introduction

In Africa, over 42 million tons of maize and 20 million tons of sorghum were produced in 2002 (FAO, 2003). Currently, in Ethiopia, these crops are grown on an estimated area of 2.4 million hectares (CSA, 2000), contributing about 41% of the country's annual grain production. The production of sufficient food for farmers in drought-prone areas of Ethiopia is a major challenge. Therefore, improving the production of maize and sorghum crops could play a great role in enhancing food security.

In Ethiopia, sorghum has a vast genetic diversity and is the dominant crop in the lowlands (< 1500 m a.s.l.) where drought and poor harvest are common (Birhane, 1977), and it is second to *tef* as source of *injera*, the national dish in Ethiopia. The Amhara state is the second biggest producing state of both maize and sorghum in Ethiopia (CACC, 2003).

Despite their importance, these crops suffer great yield losses due to stemborers and other insect pests. Among the insect pests that attack sorghum and maize in Africa, the lepidopterous stemborers are the most injurious (Kfir *et al.*, 2002). In Ethiopia, three species of stemborers, namely *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) attack maize and sorghum (Assefa, 1985). Recent surveys in Ethiopia indicated the existence of two others, namely *Sesamia nonagrioides botanephaga* Tams and Bowden (Lepidoptera:

Noctuidae) and *Rhynchaenus niger* (Horn) (Coleoptera: Rhynchophoridae) (Emana, 2002). In the Amhara State, stemborers remain the major pests of maize and sorghum (BOA, 1999). Crop losses reported in Ethiopia vary with researchers, locations, crop species attacked and borer species and it ranges from 15-100% (Assefa, 1989; Tadesse, 1989; Gashawbeza and Melaku, 1996; Emana, 1998b).

To date, non-pesticide pest management tactics such as biological control agents, host plant resistance and habitat management are advanced in many pest management tactics. Habitat management and/or cultural practices stabilize the habitat maintaining indigenous natural enemies in the otherwise fragile ecosystem (Kfir *et al.*, 2002). The effect of cultural practices such as planting times must be assessed in order to guarantee their success (CTA, 1997). Reports indicate that the time of planting has a pronounced effect on infestation levels and subsequent yield loss caused by stemborers in maize in several countries (Van Rensburg *et al.*, 1985; Assefa *et al.*, 1989) and generally on cereals (Glen, 2000). This is due to the occurrence of distinct periods of moth flight. Planting should be carried out at a time when the susceptible stage of the crop coincides with the lowest moth flight. The precise effects of different sowing dates that result from the interactions of ovipositing females with growing crops vary with locations and seasons. In Ethiopia and Nigeria, early-planted maize is less attacked, while this was not the case in Tanzania and Malawi (Harris and Nwanze, 1992). Differences in infestation due to the interaction of sowing date and location were clearly observed in southern Ethiopia, but there was no information for northern Ethiopia, including the Amhara state. The right planting time is location specific and in drought-prone areas farmers might not have more choice than planting at the first effective rainfall. Thus time of planting might only be manipulated in areas with extended rainy seasons or where supplementary irrigation is possible, or where two or more successive seasons prevail in a year. Currently, the Amhara State is introducing water- harvesting techniques at a regional scale. Moreover, knowledge of a planting time associated with heavy borer occurrence helps in host plant resistance screening and habitat management trials (F. Schulthess, Nairobi, Kenya). This helps to avoid the need for expensive laboratory rearing and artificial infestation.

Most previous stemborer management research in Ethiopia did not include the Amhara state except some effort by Emana (2002) on the distribution of borers and their natural enemies The Amhara State is one of the few major grain producing areas in the country, which was largely neglected, though it suffers similar pest problems (Shegaw *et al.*, 1999; Melaku Wale, pers. obs.). The present study tried to determine the effect of planting time on stemborers and associated biotic factors as it applies to the Amhara state of Ethiopia.

7.2 Materials and methods

7.2.1 Study site

The study was conducted in the Amhara National Regional State (ANRS), which is located in north-western part of Ethiopia, at two agro-ecologically distinct locations: i.e., at Addis Zemen and Zema. It was conducted at Zema in 2003, and at Addis Zemen in 2003 and 2004. Western Amhara is the major maize producing area in the state, and in Ethiopia. However, borer infestation is low in the maize dominated area of western Amhara, and instead sorghum dominated areas were chosen where borers make economic damage. Specific details of the sites are given in Chapter two of this thesis.

7.2.2 Experimental set up

Planting time naturally varied according to the onset of rainfall at a particular location and season. However, the population dynamics of the borers followed exactly the same pattern, no matter how the time of planting or season varied. The dates were termed as early, i.e., first effective rainfall, mid and late, in both years and locations, where rains start a bit earlier or later than expected. In 2003, early, mid and late were May 5, June 19 and July 10 in Addis Zemen, and July 4, July 14 and July 24 in Zema, respectively; in 2004, early, mid and late were June 25, July 7 and July 24. Each treatment was planted with non-host border plant, *Guizotia abyssinica* L., which grew tall and isolated the crop within it, to prevent interference among treatments. The test crop was sorghum. The standard sorghum variety, *Birmash*, was used. It is adapted to 1600-1900 m a.s.l., rainfall of 900-1200 mm; it is a red seeded variety for areas of intermediate elevations and higher rainfall. It matures in 147-181 days. It was planted on a Randomised Complete Block Design (RCBD), replicated 4 times. Plots were 6 m long × 8 rows × 0.75 m row spacing. Spacing between replicates and plots were 3 m and 2 m, respectively. Sorghum seeds were drilled along the row at a seed rate of 10 kg/ha and later thinned to a plant spacing of 0.30 m, equivalent to 44,444 plants/ha. However, because of tillering, the numbers were much higher than it was later in the season. .

7.2.3 Sampling procedures

Non-destructive and destructive sampling methods were carried out at various stages of the sorghum crop: seedling, knee height, flag leaf, heading, grain filling and harvest stages. The plants were dissected to find all stages of borers and natural enemies, which were counted and identified. The recovered borers were taken to the laboratory and reared until the emergence of adults or natural enemies. At the same time, plant height and diameter, number of leaves, internodes, holes, damaged and undamaged internodes per plant, and percent stem tunnelling length were recorded. For destructive sampling, at the various stages before harvest, 10-20 plants per plot were randomly cut at ground level from the four outermost rows, two rows on each side of the plot. At harvest, 100 plants were sampled for destructive sampling, peduncle damage, and head weight. Grain yield was recorded per plot (36 m^2) and extrapolated per ha basis.

7.2.4 Statistical analysis

An analysis of variance (ANOVA) was conducted using the mixed model (SAS, 1999-2000) to assess the effects of planting times, and crop growth stages, on borer numbers, damage levels, and plant growth variables. Analysis of variance (ANOVA), using the general linear model (GLM) procedure of SAS was performed on head weight and grain weight per plot (SAS, 1999-2000). Means were separated using the SNK at a significance level of 0.05. Borer numbers and their damage symptoms were compared among and between planting times and the crop growth stages. Stepwise regressions analyses were done between cob and head weight and plant growth parameters, damage variables and borer density. In circumstances where assumptions for normality were not met, transformations were routinely conducted before analysis. Percentage data were square root (x+1), and counts log (x+1) transformed to stabilize variance. Significance was always set at P=0.05 for all analysis.

7.3 Results

Although planting time varied each year according to the onset of rainfall at a particular location and season, the population dynamics and damage levels of the borer followed the same pattern.

7.3.1 Effect of planting time on *B. fusca* density

Borer density generally declined with delay in planting time (Table 7.1). Although sampling was conducted at various growth stages of the crop, some of the stages did not have infestations. Therefore, there was no noticeable stemborer infestation prior to the knee height stage of the crop at both locations. Then borer density significantly increased until grain filling stage of the crop, declining thereafter up to harvest (Table 7.1; Fig. 7.1). At grain filling stage, a mean of 7, a maximum of 23, and at other growth stages 7 to 17 larvae per plant were recorded. The interaction between crop growth stages and planting times were also significant ($P<0.05$). Borer density was higher in 2003 than in 2004 both on planting times and growth stages (Table 7.1). *R. niger* borers were higher in early planted crop than late planted one ($F=3.05$, $p<0.05$); similar trend was observed by *B. fusca*.

7.3.2 Effect of planting time on nematode density and parasitism

Abundance of larval parasitoids was not worth analyzing or reporting, apart from mentioning their mere occurrence at a particular occasion, time and place. *C. sesamiae* and *Dolichogenidea fuscivora* were such examples. They were found on few plants at later growth stages of the crop. Nematodes were the only known efficient parasites of stemborers in western Amhara. They were observed mainly at the vegetative stage, i.e., earliest crop growth stages, when moisture was still abundant. A maximum of six nematodes per plant was recorded at the vegetative stage of the crop. They virtually disappeared at later crop growth stages, when moisture levels decreased. Both nematodes density and parasitism, and earwigs' population did not significantly vary with planting time (Table 7.2).

Table 7.1 Least square means of *B. fusca* density (± SE) per plant at different planting times and growth stages of sorghum in western Amhara, Ethiopia, 2003-2004.

	Addis Zemen		Zema
	2003	2004	2003
		Planting time*	
Early	3.30±0.20aA	2.25±0.13aB	3.74±0.19a
Mid	2.91±0.19aA	1.92±0.12abB	2.51±0.19b
Late	2.76±0.19aA	1.62±0.14bB	1.90±0.19c
F value	2.01	5.39	2.35
P value	0.1347	0.0048	0.0490
		Growth stage	
Knee height	1.60±0.34cA	0.21±0.10cB	-
Flag leaf	1.18±0.25dA	0.27±0.14cB	1.11±0.21c
Heading	4.16±0.24bA	2.31±0.11aB	3.40±0.19b
Grain filling	6.92±0.24aA	2.79±0.08aB	4.89±0.19a
Harvest	2.30±0.12cA	1.58±0.12bB	2.41±0.14c
F value	97.21	123.03	56.07
P value	<.0001	<.0001	<.0001

Means within a column within planting time or growth stage followed by the same letter(s) are not significantly different from each other (SNK); similarly, means within rows within Addis Zemen location followed by the same upper case letter are not significantly different (SNK); * specific planting times, early, mid and late as stated in the Materials and methods.

Table 7.2 Least square means (±SE) of borer parasitism due to nematodes, nematodes/ plant, and earwigs/ plant at different planting times and growth stages of sorghum in western Amhara, Ethiopia, 2003-2004.

Planting time	% Borer parasitism by nematodes	Nematodes/ plant	Earwigs/ plant
Early	5.66±2.25a	0.07±0.03a	0.01±0.005
Mid	6.21±2.25a	0.09±0.03a	0.01±0.005
Late	5.82±2.29a	0.08±0.03a	0.00±0.005
F value	0.02	0.14	0.40
P value	0.9847	0.8663	0.6683

Means within a column within planting time or growth stage followed by the same letter(s) are not significantly different (SNK).

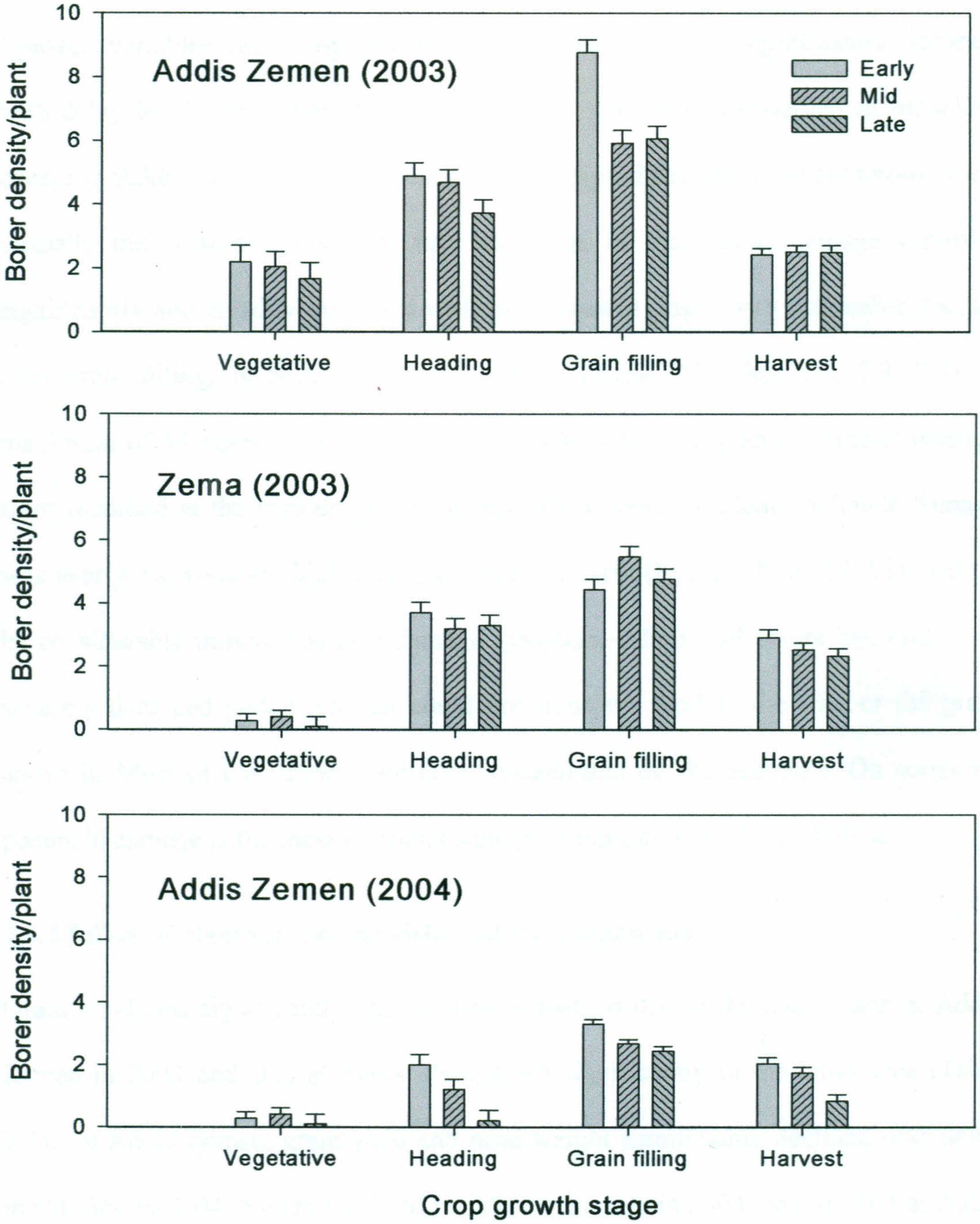


Fig. 7.1 Mean borer density at different growth stages and planting times at Zema and Addis Zemen, 2003-2004.

7.3.3 Effect of planting time on borer damage variables

Damage variables (tunneling, holes, and internode damage) significantly declined with delay in planting time (Table 7.3). Similar pattern was observed in tunneling except in Addis Zemen in 2003, which was not significant. Damage symptoms were virtually insignificant before the flag leaf stage of the plants; damage variables significantly and steadily increased with plant growth stage, with noticeable decline after grain filling, in both years and locations (Table 7.3; Figs. 7.2, 7.3, 7.4). A maximum of 34 holes per plant, and 100% each of tunneling and internode damage were recorded at the various growth stages of the sorghum plant. Peduncle damage was nearly significantly higher on plots planted early ($F=3.38$, $P=0.0542$) indicating its considerable importance as a damage symptom. Almost all plants had broken or severely damaged peduncles that could not transport food to the sink or the grain above it. Most of the larvae were also concentrated on the peduncle. On sorghum, peduncle damage is the most injurious damage symptom in western Amhara.

7.3.4 Effect of planting time on yield and its components

Grain yield was significantly higher in plots planted during the mid-season at Addis Zemen in 2003 and also at Zema, though not significantly in the latter area (Table 7.4). In Addis Zemen, grain yield and head weight significantly declined with delay in planting in 2004. Yields and head weight were lower in 2004 than in 2003 at Addis Zemen. Head weight did not follow a pattern that could apply to both locations.

7.3.5 Relationship between head weight and plant growth parameters, damage variables and borer population

Stepwise regression analysis indicated that increasing basal diameter of the plant increased head weight; on the other hand, increasing borer population, number of holes, internode damage, peduncle damage and percent tunneling significantly reduced head weight (Table 7.5). When the regression analysis was done by year and planting time, exactly the same result was obtained.

Table 7.3 Least square means (±SE) of borer damage variables at different planting times* and growth stages of sorghum in western Amhara, Ethiopia, 2003-2004.

	% Stem tunneling			**# Holes/ plant**			**% Internode damage**	
	Addis Zemen		Zema	Addis Zemen		Zema	Addis Zemen	Zema
	2003	2004	2003	2003	2004	2003	2004	2003
Planting time								
Early	64.3±2.5aA	34.5±2.0aB	59.9±2.02a	15.6±0.6aA	6.7±0.3aB	14.5±0.5a	39.9±1.9a	52.0±2.03a
Mid	63.5±2.4aA	31.0±1.8aB	58.8±2.02a	17.6±0.6aA	5.3±0.3bB	12.6±0.5b	35.9±1.8a	57.3±2.03a
Late	63.5±2.4aA	25.1±2.2bB	45.9±2.02b	13.2±0.6bA	3.3±0.5cB	10.0±0.5c	26.4±2.2b	40.9±2.03b
F value	0.03	5.23	14.80	11.57	17.36	16.78	11.97	17.07
P value	0.9657	0.0057	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Crop growth stage								
Flag leaf	18.2±1.9cA	1.1±2.1cB	33.9±2.0c	8.0±0.8cA	0.5±0.4cB	10.9±0.7b	6.1±2.1b	34.4±2.3b
Grain fill	29.7±1.8bA	34.3±1.3bA	51.7±2.0b	13.1±0.8bA	7.2±0.2aB	12.6±0.7ab	40.2±1.3a	51.2±2.3a
Harvest	82.3±0.9aA	43.7±1.7aB	67.0±1.4a	17.9±0.4aA	5.3±0.3bB	12.9±0.5a	44.0±1.7a	57.3±1.6a
F value	691.29	132.01	96.69	60.15	121.64	3.46	116.93	35.26
P value	<.0001	<.0001	<.0001	<.0001	<.0001	0.0324	<.0001	<.0001

* dates as stated in Table 1; means within a column within planting time or growth stage followed by the same letter(s) are not significantly different (SNK); similarly, means within rows within Addis Zemen location followed by the same upper case letter are no significantly different (SNK).

Table 7.4 Least square means (±SE) of grain yield (kg ha^{-1}) and head weight (g/ plant) at different planting times* of sorghum in western Amhara, Ethiopia, 2003-2004.

	Grain yield (kg/ ha)			Head weight (g/ plant)		
	Addis Zemen		Zema	Addis Zemen		Zema
	2003	2004	2003	2003	2004	2003
Early	1453.7±130.51b	368.68±122.16ab	829.63±324.0a	34.07±2.91a	17.64±1.48a	19.19±1.97b
Mid	2114.82±130.51a	605.21±122.16a	1221.48±324.0a	32.94±2.91a	6.55±1.44b	29.38±1.97a
Late	1435.19±130.51b	13.89±122.16b	707.22±324.0a	34.99±2.91a	2.05±1.60b	19.86±1.97b
F-value	8.80	5.94	0.69	0.12	27.87	8.35
P-value	0.0164	0.0227	0.5385	0.8843	<.0001	0.0003

* dates as stated in Table 1; means within a column within planting time or growth stage followed by the same letter(s) are not significantly different (SNK); similarly, means within rows within Addis Zemen location followed by the same upper case letter are no significantly different (SNK).

Table 7.5 Effect* of plant growth parameters and damage variables on sorghum head weight in western Amhara, Ethiopia, 2003-2004.

	b	F	P value
Y Head weight (g/ plant)			
X_1 Stem diameter (cm)	10.68	27.27	<.0001
X_2 Borer density/ plant	-2.91	15.84	<. 0001
X_3 No. holes/ plant	-0.64	21.04	<.0001
X_4 % internode damage	-0.11	11.35	0.0008
X_5 Peduncle damage	-9.00	9.77	0.0019
X_6 % stem tunneling	-0.38	80.28	<.0001
Intercept = 3.59, r^2 = 0.22, N = 684			

* Stepwise multiple regressions, *b* values are partial regression coefficients.

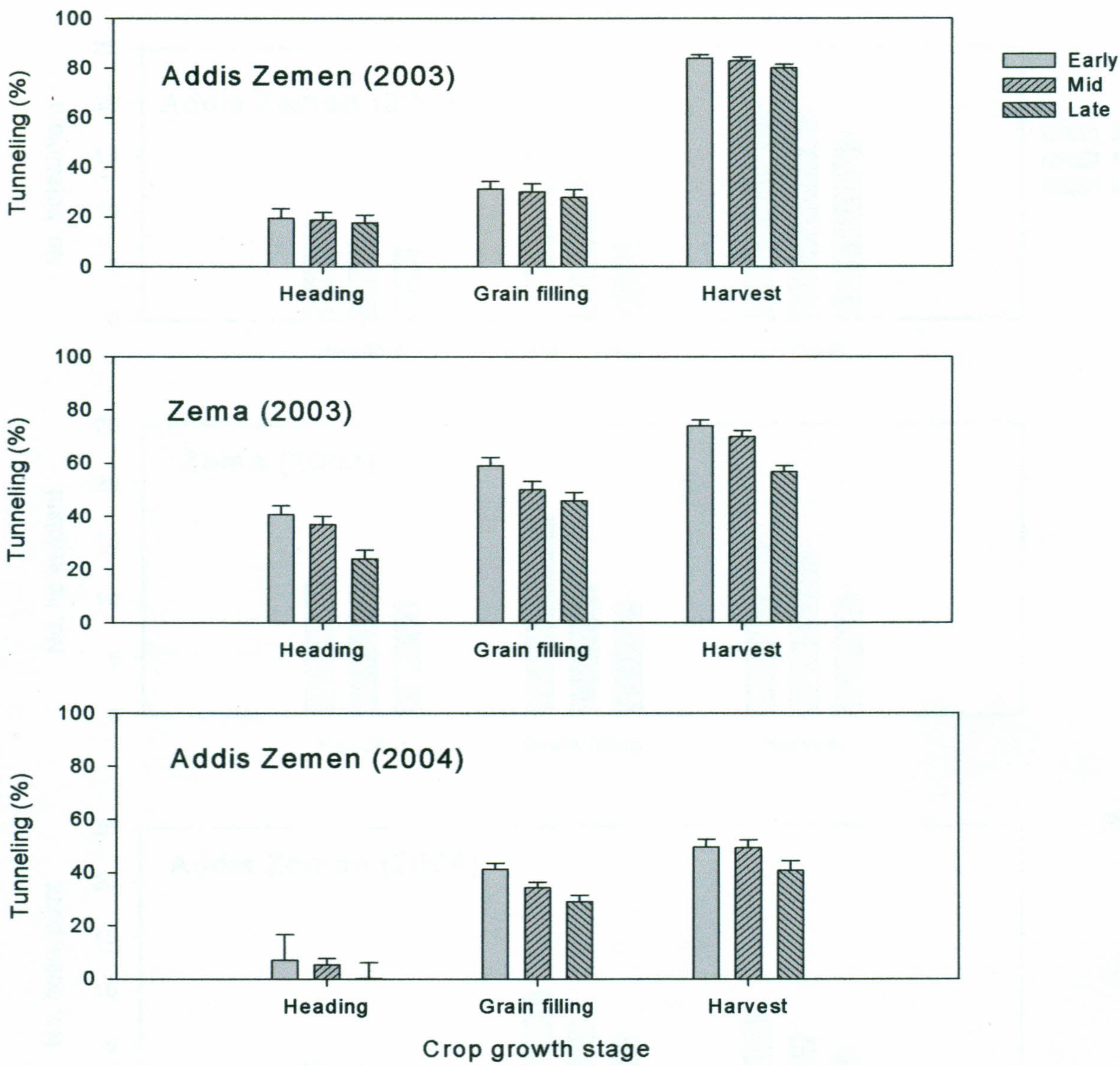


Fig. 7.2 Mean percent tunneling at Addis Zemen and Zema, 2003-2004.

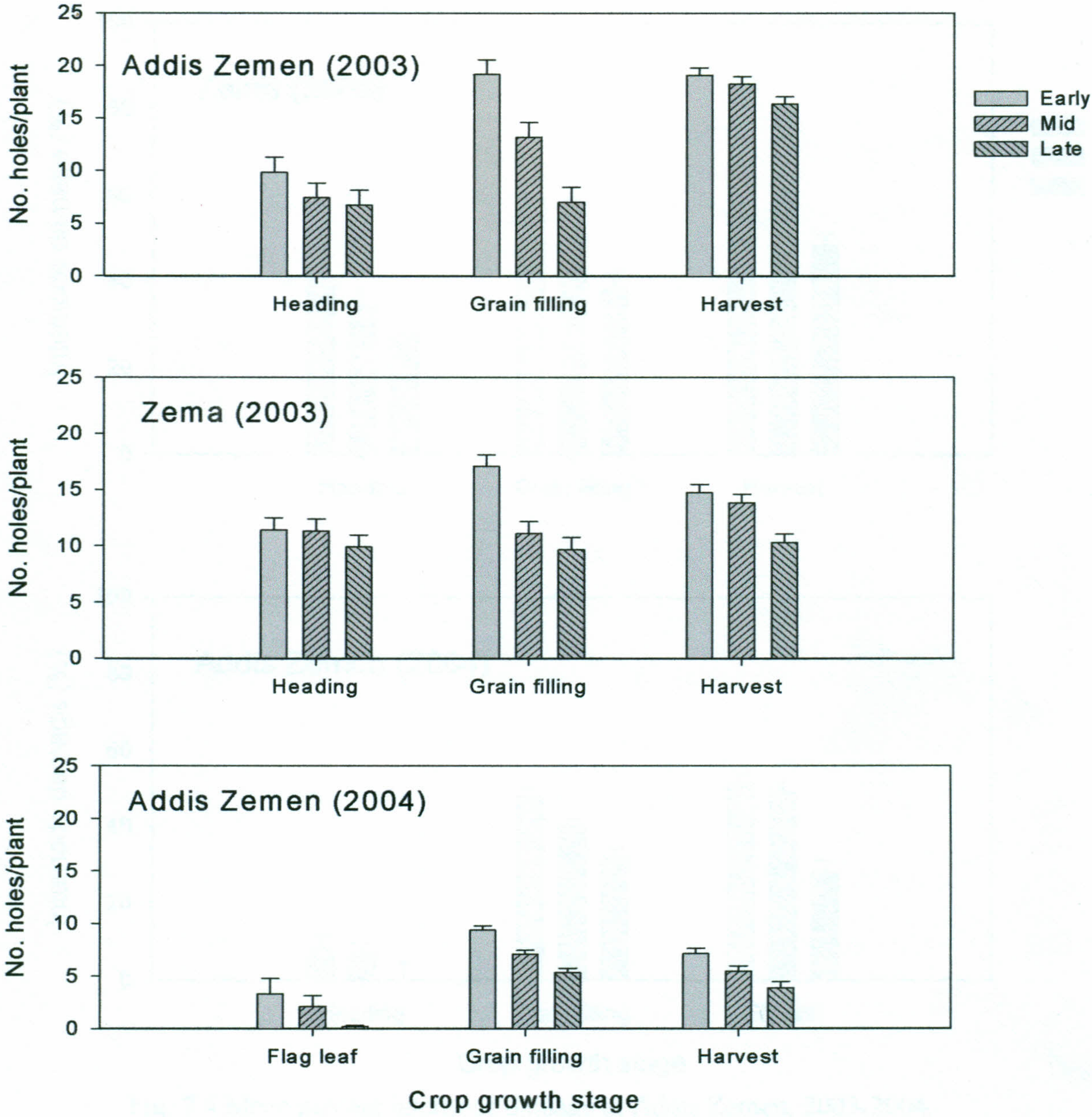


Fig. 7.3 Mean number of holes per plant at Addis Zemen and Zema, 2003-2004.

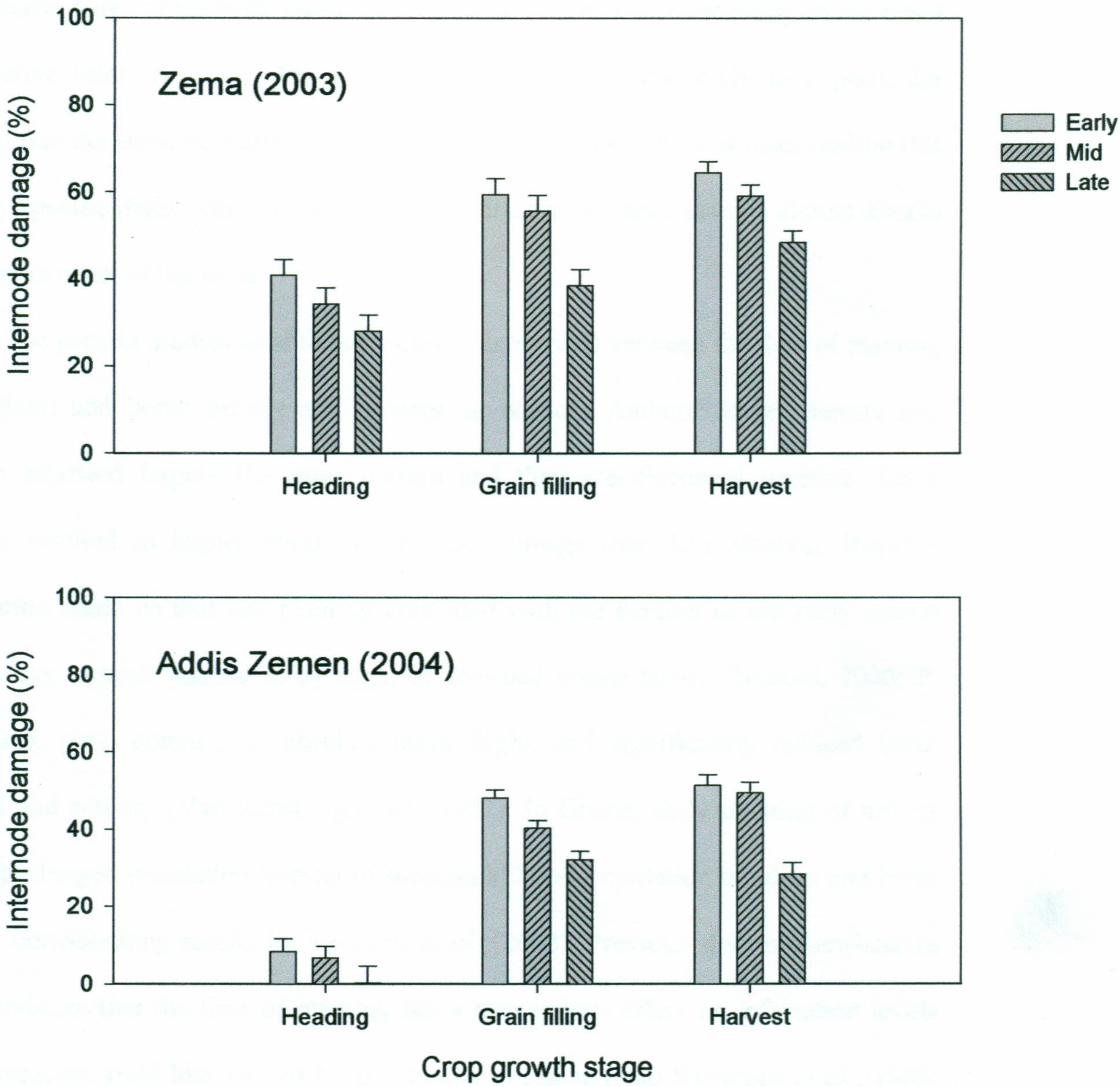


Fig. 7.4 Mean percent internode damage at Addis Zemen, 2003-2004.

7.4 Discussion

The specific dates of planting varied at each location and year depending on the onset of effective rains. However, the pattern of the results of the study in a particular location was the same no matter when the onset of rains was, and it is discussed on this ground. Specific dates need not be the basis for discussion, since there is almost always variation in onset of the rains.

The present studies established a clear relationship between the date of planting of sorghum and borer density and damage in western Amhara. Borer density and damage followed largely the same pattern and they are discussed together. Early planting resulted in higher borer density and damage than late planting. Possible explanation could be that late planting coincided with the deepest of the rainy season when heavy rainfall washed away eggs, or drowned young larvae (Bonhof, 2000; F. Schulthess, pers. comm.), or checked moth flight, and significantly reduced borer survival and activity (Van Rensburg *et al.*, 1987). In Ghana, early planting of millets caused prolonged infestation leading to substantial borer population build-up and borer damage corroborating results by Tanzubil *et al.* (2002). Previous studies elsewhere in Africa indicate that the time of planting has a tremendous effect on infestation levels and subsequent yield loss caused by stemborers in maize (Van Rensburg *et al.*, 1985; Assefa *et al.*, 1989). However, response to variation in planting time is location specific. In southern Ethiopia, western Kenya and in Nigeria, early-planted maize was less attacked, while this was not the case in Tanzania and Malawi (Seshu Reddy, 1989; Assefa *et al.*, 1989; Harris and Nwanze, 1992). In western Kenya, farmers practice early and simultaneous planting (Bajwa and Schaefers, 1998). According to Kumar (1984), planting maize at the beginning of the first rainy season to avoid borer attack was so effective that no additional control measure was required. Contrary to the results of the current study in the Amhara State, in southern Ethiopia, Assefa *et al.* (1989) and Assefá (1990) reported that early sowing in mid April had significantly lower infestation of first generation larvae of *B. fusca.* Similarly, in Nazareth area, central Rift Valley Ethiopia, *B. fusca* population and damage increased as planting was delayed, but *C. partellus* did not (Melaku, 1999). These contradictory results in different countries, locations and regions indicate that generalizations could not be made based on the results from one region or location, and instead require specific investigation in each region.

The decline in borer density in 2004 could be explained by rainfall pattern. The first effective rainfall and the total rainfall in the planting month of June was 26-33% higher in 2003 than at the same time in 2004. This increased rainfall could have encouraged more diapause larvae to emerge and start infestation in 2003 than 2004 as suggested by Chabi-Olaye *et al.* (2005c).

Borer density increased linearly up to grain filling but declined slightly at harvest. This is probably because most borers had completed their life cycle and had already left the plant by harvest time (Setamou *et al.*, 1995). Leaf damage symptoms, including deadheart formation, were low due to late borer occurrence. Thus damage symptoms were observed in the form of tunnels, holes, internode and peduncle damage, rather than leaf damage and deadheart formation. Much of western Amhara is less of a hotspot for stemborers but sorghum, especially when planted early, suffered late in the season, when rains leave. Borer numbers and damage symptoms were minimal in the first three months of the crop growth but just as the crop was about to flower, the borers appeared in abundance from nowhere, and damaged the crop completely, especially the crop planted early. This implies that early maturing crops such as early maize varieties could escape such damage. Unfortunately, sorghum is mostly slow in maturing (Melaku Wale, in press), and therefore, early planting of sorghum cannot help to escape borer attack. So, in sorghum, the reproductive stage is the most susceptible stage for borer attack. In contrast a study conducted at the same time on the effect of intercropping maize with legumes and oil crops indicated that the borers and damage levels were higher during the vegetative stage than during earlier and later stages (Melaku Wale, unpub.). Sorghum, unlike maize, was suitable for borers until late in its growth stage, and also continued growing for a long time increasing the magnitude of borer damage. This further indicates that early damage symptoms such as deadheart formation and leaf damage are unlikely to be important, and instead damage symptoms like tunneling, holes and peduncle damage will be the most important damage variables. This shows the clear difference between the two crops with respect to reaction to borer attack.

In general, crop plants planted early in the season suffered greater damage than those planted later. This could be due to the longer time of exposure of early-planted crops to borers as observed by Tanzubil *et al.* (2002). Van Hamburg (1979) concluded that in the Transvaal, South Africa, sorghum should be planted after mid-October to avoid infestation from the first moth peak during the vulnerable flag leaf or funnel stage. Planting after mid-December will expose the funnel stage to the second large moth peak (Van Hamburg, 1979).

Higher nematode parasitism was recorded in plots planted during the mid-season, though not significant. This coincided with the time when rainfall was high indicating that the parasites are heavily dependent on abundance of moisture (Kaya and

Gaugler, 1993; Poinar and Polaszek, 1998). Peak nematode parasitism of *B. fusca* was observed during the wettest months of the rainy season and did not show clear relationship with planting time. In the long term, their commercial application may help eliminate the borer inoculum in the later part of the growing season up on the commencement of the dry season. Besides, nematodes were observed parasitizing 2nd to 3rd instars larvae, which coincides with the earliest stages of borer infestation. Late in the season borers grow older, bigger, and more numerous, and are probably resistant to nematode parasitism. Thus on sorghum, the application of nematodes, would be recommended in late August, when borers start their wave of attack. That was the time when nematodes were observed actively parasitizing the borers, especially *B. fusca*.

Mid season plantings gave significantly better yield than other dates. Early planted sorghum suffered bird attack while late planted ones suffered lack of sufficient moisture, confounding and complicating the effect of borers in the yield.

Stepwise regressions showed a clear association between yield and damage, plant growth variables, and borer numbers. Regression analysis of yield gave negative relation with tunneling, peduncle damage, internode damage, holes and borer density and positive with stem diameter. Both plant height and internodes per plant were out of the equation. This agrees with the results of studies by various authors on a range of African borer species (Bosque-Perez and Mareck, 1991; Gounou *et al.*, 1994; Setamou *et al.*, 1995; Kalule *et al.*, 1997; Ndemah *et al.*, 2000; Chabi-Olaye et at., 2005b).

Conclusion to be drawn from these studies is that, contrary to much of the available information in East Africa and southern Ethiopia, late planting clearly reduced borer occurrence. In western Amhara, only one effective rainy season exists, the length of which varies significantly between locations (i.e., short or extended rainy season). Depending on these differences in climate, it appears reasonable to conclude that in some areas of western Amhara, where the degree of uncertainty in the pattern of rains is considerable, sorghum planting should be done at the first onset of rains, despite the higher borer incidence, while in areas of longer (6-month) rainy season, especially in areas such as Ayehu district, staggering the time could be acceptable. Seshu Reddy (1990) recommended early planting in semi-arid areas because rainfall is variable and unpredictable. He further explained that even though the late planted crop may be free from stemborer damage, yields will be low. However, locations may vary significantly in reaction to these treatments and additional studies specific to an area may be required before any valid recommendations are made in western Amhara. Future study areas of interest include: investigate the mechanism responsible for the absence of borers during the wet months (the discovery of the agents, whether biotic or abiotic), the species composition, biology and ecology of nematodes, virulence test, mass production, packaging and distributing nematodes to growers, more population dynamics study of borers in the sorghum growing areas of East Gojam zone, and in the maize growing area of Lake Tana, western Amhara by planting at various times of the year.

CHAPTER EIGHT

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Stemborers are pre-eminent among Africa's most damaging cereal pests, and have, therefore, attracted a great deal of attention from economic entomologists for most of the century (Polaszek, 1998). The methods, philosophies and paradigm of stemborer management have changed drastically over years. Awareness towards the danger posed by chemical pesticides and emphasis to arthropod biodiversity has been encouraging.

In Ethiopia stemborers are major constraints to maize and sorghum production causing 20-50% yield loss (Emana, 2002). Reducing these losses by half would eliminate the country's chronic food deficit. Scientists have devised several alternative methods of borer management (Kfir, 1992; Overholt *et al.*, 1997; Khan *et al.*, 2001). Nevertheless, borers still remain the major pests of cereals, one of the reasons being lack of research attention in some parts of the world. In Ethiopia, studies on stemborers and other pests have been conducted in central, eastern and southern parts of the country (Birhane, 1977; Assefa, 1982, 1985, 1988a, 1989, 1990, 1991; Abraham *et al.*, 1993; Emana, 1998b; Melaku, 1999; Ferdu *et al.*, 2001). Despite the widespread occurrence of stemborers and the damage they cause, little is known of stemborers in the major grain producing area of the Amhara state in Ethiopia (Shegaw *et al.*, 1999; Melaku Wale, in press). Ethiopia is a relatively large country and possesses huge ecological and biological diversity and agricultural complexity; these factors imply huge variation in pest management strategies that are specific to particular areas (Abate, 1996). Therefore, in the present study, baseline information on the importance and geographic distribution of stemborers and their natural enemies were established, some of the interactions among a range of biotic and abiotic factors including soil fertility, host plants, cropping systems, timing of planting, borers species and beneficial organisms were determined in the stemborer ecosystem of the Amhara State, which are prerequisites for environmentally sound stemborer management. The major stemborer species and the most abundant natural enemies with respect to different ecozones, administrative zones and districts of the Amhara State were identified and quantified, which are the springboard for all management activity. Such big differences in stemborer level of infestation, species composition including their natural enemies among ecozones, administrative zones, districts, varieties and growth stages of maize and sorghum of the Amhara state indicate the need for specifically designed management strategies based on these criteria.

In the cool-humid western Amhara, unlike in the semi-arid eastern Amhara, farmers commonly use chemical fertilizers to grow crops. Response to N fertilization in both stemborer numbers and grain yield was observed in western Amhara, contrary to eastern Amhara, where the grain yield loss linearly decreased with increasing fertilization. This shows the dual benefit of fertilization both in terms of reducing the level of yield loss caused by stemborers as well as increasing the yield per unit area.

The effect of widely practiced indigenous cropping systems on stemborer was studied with specific differences in eastern and western Amhara. The farming systems of eastern and western Amhara regions are different. Cropping systems with low stemborer incidence and high natural enemy performance were identified for each region. Farmers in the Amhara state have strong tradition in growing a mixture of crops on a piece of land. They are doing this to avoid or minimize the impact of disasters such as pests, natural calamities (hail damage, etc.), to maintain soil fertility, and to diversify the family's nutrition or as a cash crop. Generally, stemborer incidence was lower on plots with intercrops, especially mustard plots. Intercrops have a number of roles to play including, minimizing pest damage, encouraging the activity of natural enemies, promoting biodiversity, increasing soil fertility and serving as source of cash. Since different intercrops differ in the specific advantage they offer, including pest control, farmers need to balance their specific interests in promoting these cropping systems.

Previous studies have established significant relationship between planting time and borer infestation (Van Rensburg *et al.*, 1988b; Assefa *et al.*, 1989). This has been attributed to distinct periods of moth flight which also is location specific (Ebenebe *et al.*, 2000). In Ethiopia and Nigeria, early-planted maize is less attacked, while this was not the case in Tanzania and Malawi (Harris and Nwanze, 1992). In the current study, in contrast to southern Ethiopia, early planted sorghum suffered significantly higher damage than mid and late planted ones in the cool-humid western Amhara. The relatively high rainfall, cool climate and natural enemies, especially the nematodes that are common during the peak rainy season all coincide with late and mid planted crop and might have contributed to the low borer incidence on the late sown crop. Furthermore, the diapause generation that attacks first planted crop may have contributed to the heavy infestation on the early planted crop. Since rainfall pattern cannot be predicted accurately staggering planting time can be advisable only in areas of western Amhara where there is extended rainfall or in eastern Amhara where there are two separate seasons in a year that require recommendations when to plant sorghum and maize in relation to borer damage.

C. flavipes was widespread in the semi-arid ecozone of eastern Amhara. It was not reported in Ethiopia until 1998 (Mulugeta, 2001). It was first reported in Ethiopia a year later at a relatively lower scale, i.e., just 7.4% parasitism level (Emana, 2002). In the current study a two year, 2003 and 2004, overall mean of 30% parasitism was recorded at the reproductive stage of the crop. This indicates an ongoing colonization of eastern Amhara by *C. flavipes*, and one would only wonder when, where and at what level of parasitism is it going to reach equilibrium. It can be argued that since *C. flavipes* is also reported to parasitize *B. fusca* (Emana, 2002), while others claim that it does not (Charles Omwega, ICIPE, Nairobi, pers. comm.), more study is required on the relationship between them. If it proves encouraging, there can be a possibility to release the parasitoid in western Amhara where *B. fusca* is the only dominant borer species. However, most other studies in Africa indicate that *C. partellus* is the preferred host for *C. flavipes*. Future studies should also focus on egg parasitoids, which are said to be the most important mortality factors in West Africa (Fritz Schulthess, pers. comm.). The current study has established that stemborers are of minor economic importance in much of the cool-humid western Amhara. The underlying mechanisms, biotic or abiotic factors, for the low borer incidence especially during the wet months must be investigated. Similar studies should include aspects such as species composition, biology, ecology, and economic importance of coleopteran borers and nematodes, virulence test, mass production, packaging and distributing nematodes, *C. flavipes* impact assessment in eastern Amhara, an authoritative and complete inventory of the stemborer species composition, their indigenous parasitoids, predators, pathogens and nematodes with the assistance of a biosystematist else where in the world, introduction, testing, release and monitoring of other exotic parasitoids such as

Sturmiopsis sp. and others into the region, setting up a full-fledged laboratory in the Amhara state mandated to stemborers biological control, and field-work should concentrate at hot spots like the whole of eastern Amhara, the Nile gorge and North Gondar zone (Kola Diba).

Furthermore, studies on population dynamics of borers in the sorghum growing areas of East Gojam zone, and in the maize growing area of Lake Tana, West Gojam zone, western Amhara (including the small rains around April and the main season from June to September). Determining the yield loss on long maturing sorghum varieties by planting an experiment during the short rains in April in eastern Amhara is top priority. Studies on the mechanism of borer reduction due to intercrops, testing mustard in eastern Amhara, and the economic analysis of intercrops, and the impact of planting times on stemborer infestation at different agroecological zones are suggested.

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APPENDICES

Appendix 4.1 Number of plants sampled and dissected per survey region, crop type, zone and growth stage.

	2003	2004
	Regions	
Eastern Amhara	1273	2592
Western Amhara	1748	1073
	Crop type	
Maize	558	493
Sorghum	2433	3172
S. arundinaceum	20	-
Sorghum/ maize	10	-
	Zone	
East Gojam	558	227
West Gojam	373	410
South Gondar	158	109
North Gondar	645	327
North Shoa	193	385
Oromiya	369	719
South Wolo	327	508
North Wolo	384	980
	Growth stage	
Seedling	-	1238
Knee height	666	468
Flag leaf / tasseling	125	112
Grain filling	451	585
Harvest	1833	1194

Appendix 4.2 Type 3 tests of fixed effects table, the mixed model procedure of SAS on borer density (study of the distribution and importance of cereal stemborers and their natural enemies in the Amhara State, 2003-2005).

a) Total borers/ plant

Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	48.4	13.33	0.0006
Zone	3	13	0.77	0.5315
Crop growth stage	3	471	9.47	<.0001

Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	172	15.29	0.0001
Zone	7	8.23	1.91	0.1895
Crop growth stage	5	4715	113.30	<.0001

b) Coleopterous borers/ plant (on sorghum)

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	193	0.35	0.5571
Zone	7	9.23	1.25	0.3690
Crop growth stage	5	4039	9.43	<.0001

c) *Chilo partellus* (on sorghum)

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	169	12.10	0.0006
Zone	7	8.57	4.10	0.0292
Crop growth stage	5	4902	111.56	<.0001

d) *Busseola fusca*

Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	46.5	16.62	0.0002
Zone	3	14.4	1.01	0.4170
Crop growth stage	3	507	7.77	<.0001

Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	172	6.54	0.0114
Zone	7	7.24	3.85	0.0457
Crop growth stage	5	4054	28.24	<.0001

e) *Sesamia calamistis*

Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	41.4	0.09	0.7666
Zone	3	22.7	0.42	0.7415
Crop growth stage	3	358	19.15	<.0001

Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	169	9.82	0.0020
Zone	7	146	5.22	<.0001
Crop growth stage	5	1148	8.32	<.0001

f) Nematodes/ plant

Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	46.2	0.12	0.7271
Zone	3	51.5	0.25	0.8593
Crop growth stage	3	216	2.17	0.0926

Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	266	0.62	0.4313
Zone	7	228	0.60	0.4313
Crop growth stage	5	1409	9.82	<.0001

Appendix 4.3 Type 3 tests of fixed effects table, the mixed model procedure of SAS on borer damage (study of the distribution and importance of cereal stemborers and their natural enemies in the Amhara State, 2003-2005).

a) % Internode damage

1. Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	15.7	3.88	0.0669
Zone	2	7.82	0.02	0.9781
Crop growth stage	1	568	108.22	<.0001

2. Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	4675	7.0	0.0099
Zone	7	4675	3.30	0.0498
Crop growth stage	4	4675	351.47	<.0001

b) Holes/ plant

1. Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	18.8	2.94	0.1028
Zone	2	8.94	0.14	0.8731
Crop growth stage	1	637	30.20	<.0001

2. Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	167	11.33	0.0009
Zone	7	9.65	3.06	0.0558
Crop growth stage	5	4735	148.9	<.0001

c) % Tunneling

1. Maize

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	974	15.02	0.0001
Zone	4	974	5.60	0.0002
Crop growth stage	3	974	28.43	<.0001

2. Sorghum

Effect	DF (Numerator)	DF (Denominator)	F-value	P-value
Year	1	160	8.89	0.0095
Zone	7	8.3	2.82	0.0818
Crop growth stage	5	4242	211.32	<.0001

Appendix 4.4 *Cotesia flavipes* cocoon masses density per plant and percent parasitism of *Chilo partellus* in eastern Amhara from 2003-2004.

Zone and locality (village)	% Parasitism			# Cocoon masses/ plant		
	Mean	SE	Maximum	Mean	SE	Maximum
North Shoa						
Asfacho	12.86	2.50	100	0.24	0.04	4.0
Asfachona Chirameda	18.75	13.15	100	0.63	0.26	2.0
Balch	48.78	10.65	100	1.15	0.25	10.0
Jejeba	38.59	6.10	100	1.28	0.20	6.0
Nifasona Gusta	46.01	6.23	100	1.45	0.24	9.0
Qurangoye	22.99	7.49	85.71	0.66	0.26	6.0
Wofafrana Ambomesk	18.03	6.58	50	0.55	0.21	2.0
Zuti	17.01	3.98	100	2.75	0.77	26.0
Oromiya						
Balchina Tikure	28.79	4.18	100	1.98	0.28	8.0
Bedeno Sertie	2.38	1.67	100	0.07	0.04	4.0
Bete Ardaga	26.01	4.25	100	0.50	0.09	5.0
Chefa	4.63	3.25	50	0.05	0.03	1.0
Chefa Robit	2.00	2.00	20	0.10	0.10	1.0
Chefa trial site	11.00	11.11	100	0.10	0.10	1.0
Chiretie	19.23	5.46	100	0.48	0.15	4.0
Dedensa Sedeko	2.63	2.63	50	0.09	0.05	1.0
Fecha	11.11	6.46	100	0.15	0.08	1.0
Finchiktu	13.64	9.75	100	0.20	0.08	1.0
Gerbi	24.75	8.83	100	0.80	0.29	5.0
Gerbi Qile Goro	18.25	11.61	100	0.36	0.15	1.0
Godachele	6.88	3.28	100	0.24	0.12	5.0

Appendix 4.4 Continued …

	Mean	SE	Maximum	Mean	SE	Maximum
Hora Dildiy	66.11	10.65	100	2.90	0.75	8.0
Jara Kechema	26.96	13.47	100	0.35	0.15	2.0
Jewuha	96.50	27.15	100	2.10	0.35	4.0
Jirota	18.06	11.13	100	0.21	0.11	1.0
Kame	17.83	5.11	100	1.17	0.35	8.0
Karakore	3.56	2.76	27.27	0.40	0.31	3.0
Koladi	27.51	12.14	100	0.90	0.31	2.0
Layignaw Ataye	9.55	2.69	100	0.29	0.08	6.0
Mekua	27.78	11.11	100	0.90	0.41	4.0
Mute Fecha	5.09	3.79	33.33	0.05	0.03	1.0
Shekla	10.38	2.85	100	0.21	0.05	3.0
South Wolo						
Abicho	13.89	3.29	1001	0.52	0.11	5.0
Addis Mender	4.33	3.37	33.33	0.30	0.21	2.0
Arabo	18.79	3.32	100	0.66	0.11	6.0
Bati	26.68	3.61	100	1.83	0.31	10.0
Chorisa	5.63	3.52	100	0.07	0.04	1.0
Galisa	14.29	14.29	100	0.33	0.17	3.0
Gebuha	17.50	10.57	100	0.40	0.22	2.0
Gulbo	12.19	4.03	75	0.42	0.15	3.0
Haik	25.63	12.29	100	0.38	0.13	6.0
Harbu	24.91	9.00	100	0.68	0.20	3.0
Jare	9.18	3.04	100	0.32	0.09	5.0
Lisbo	33.33	19.25	66.67	0.30	0.21	2.0
Terefo	1.97	1.46	50	0.08	0.04	1.0
Tis Abalima	15.0	10.67	100	0.37	0.14	4.0
Wodey	10.95	7.51	66.67	0.45	0.31	3.0

Appendix 4.4 Continued …

	Mean	SE	Maximum	Mean	SE	Maximum
North Wolo						
Afasash	17.82	10.19	100	0.45	0.21	4.0
Aradom	24.50	4.53	100	0.49	0.10	6.0
Doro Gibir	19.42	4.14	100	0.77	0.16	6.0
Gedober	5.43	3.31	100	0.07	0.03	3.0
Gerado	4.72	1.52	100	0.10	0.03	2.0
Gobye	12.61	4.01	100	0.31	0.09	3.0
Hormat	13.10	5.08	100	0.17	0.05	2.0
Kobo	13.94	4.07	100	0.20	0.05	4.0
Mersa	34.43	7.74	100	0.69	0.18	7.0
Tikur Wuha	10.53	7.23	100	0.26	0.21	4.0
Woldia	23.33	13.19	100	0.30	0.15	1.0
Worekalo	10.70	4.34	100	0.33	0.12	4.0
Woremigna	22.62	6.74	100	0.47	0.18	8.0

Appendix 4.5 Mean altitude, borer density, damage and percent parasitism in the two survey regions in the Amhara state, 2003-2005.

		Mean	SE	Minimum	Maximum	t-value	p-value
				Eastern Amhara			
Altitude		1572.41	27.54	1155	2389	57.1	<.0001
Borers	*C. partellus*	2.45	0.30	1155	18.4	7.43	<.0001
	B. fusca	0.20	0.06	0	3.56	3.32	0.0013
	S. calamistis	0.04	0.01	0	1.04	2.65	0.0098
	Total borers	2.70	0.24	0	16.1	8.97	<.0001
Damage	% tunneling	16.65	1.53	0	73.18	10.68	<.0001
	% internode damage	28.75	2.35	0	85.59	12.23	<.0001
	# holes/ plant	8.50	0.83	0	43.92	10.25	<.0001
Parasitism	% parasitism by *C. flavipes*	13.85	1.81	0	96.50	7.65	<.0001
	Cocoons/ plant	1.06	0.41	0		2.57	0.0118
	# nematodes/ plant	0.20	0.20	0	8.40	1.0	0.3232
				Western Amhara			
Altitude		2020.85	35.55	1341	2584	56.84	<.0001
Borers	*B. fusca*	0.74	0.08	0	3.53	9.17	<.0001
	S. calamistis	0.04	0.02	0	1.44	1.89	0.0631
	Total borers	0.83	0.09	0	3.61	9.27	<.0001
Damage	% tunneling	10.73	1.15	0	42.91	9.32	<.0001
	% internode damage	16.32	2.18	0	68.2	7.47	<.0001
	# holes/ plant	4.36	0.51	0	18.86	8.52	<.0001
Parasitism	# nematodes/ plant	0.08	0.04	0	1.42	2.12	0.0408
	# nematodes/ borer	0.07	0.07	0	0.47	1.00	0.3600

Appendix 5.1 Some monthly climatic data in and around trials sites.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Addis Zemen						**2003**							
Min (°C)	-	-	-	-	12.2	9.8	8.1	8.2	7.5	5.7	4.4	3.8	
Max (°C)	-	-	-	-	-	27.9	24.4	23.3	26.3	29.1	30.1	30.5	
RF (mm)	-	-	-	-	-	182.2	411.3	338.5	183.9	7.9	0	0	1123.8
						2004							
Min (°C)	4.3	5.4	7.4	9.2	9.0	8.9	-	7.2	7.7	4.8	5.3	-	
Max (°C)	31	32.4	33.5	31.8	32.8	28.5	-	25.4	27.7	28.6	29.4	-	
RF (mm)	0	9.3	0.5	50.5	20	121.6	-	315.8	135.6	47.2	44.6	-	745.1
Bahir Dar*						**2003**							
RH (%)	50	45	42	36	38	67	75	77	74	60	55	51.3	
						2004							
RH (%)	-	48	42	47	46	64	73	75	72	60	59	55	
Gondar						**2003**							
Min (°C)	11.5	14.5	15.5	16.4	18.1	14.8	14.0	14.1	13.2	12.6	13.4	12.3	
Max (°C)	29.1	30.3	30.8	31.7	32.2	26.3	23.1	23.1	29.0	27.7	28.9	28.7	
RF (mm)													
						2004							
Min (°C)	12.0	12.9	15.4	16.2	16.8	14.8	13.5	13.6	12.8	13.1	13.1	12.0	
Max (°C)	29.3	29.9	31.3	30.0	31.1	25.9	23.2	30.0	25.1	26.2	27.5	27.6	
RH (%)*	39	36	29	37	34	64	-	77	69	56	49	43	

Appendix 5.1 Continued …

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kola Diba						**2004**							
Min (°C)	-	-	-	-	-	18.5	17.8	14.7	14.6	11.7	11.9	11.2	
Max (°C)	-	-	-	-	-	24.3	24.5	24.5	26.5	31.8	33.3	34.6	
RH (%)*	-	-	-	-	-	63.4	71.1	80.1	73.6	62.0	54.4	47.5	
Chewahit						**2003**							
RF (mm)	0	6.4	3.8	2.9	2	164.5	245.8	256.7	184.1	37.6	7.7	19.2	930.7
						2004							
RF (mm)	0	0.2	0	27.0	26.9	121.6	262.2	234.9	148.1	74	9.2	0.0	904.1
Chefa						**2004**							
Min (°C)	-	-	-	-	12.8	14.6	16.6	16.1	14.4	10.9	9.0	-	
Max (°C)	-	-	-	-	33.2	32.7	32.2	30.2	29.0	28.0	28.5	-	
RH (%)*	-	-	-	-	28.0	27.5	43.9	56.4	54.6	44.5	47.9	-	
RF (mm)	-	-	-	-	11.3	19.9	174.7	256.8	89.4	59.3	44.4	-	655.8

- indicates no data; * There was no RH data for Addis Zemen and Bahir Dar RH data was used instead. Similarly, Kola Diba had not rainfall data, and Chewahit rainfall data was used to represent it. Chewahit is few kms away from Kola Diba.

Appendix 5.2 Some soil physicochemical properties of trial sites (1997).

a) Eastern Amhara (represented by Chefa trial site)

Soil properties	Soil depth	
	0-20 cm	20-40 cm
pH	6.5	6.6
Total N (%)	0.18	0.16
Available P (Olsen, ppm)	29.42	22.24
Organic carbon (%)	2.242	1.968
Ca^{2+} (cmol kg^{-1})	27.86	26.84
Mg^{2+} (cmol kg^{-1})	11.22	8.45
K (cmol kg^{-1})	0.88	0.76
Na (cmol kg^{-1})	0.25	0.24
CEC (cmol kg^{-1})	46.92	37.72
Base saturation (%)	87.41	96.2
Clay	58	59
Silt	22	21
Sand	20	20
Texture	Clay	Clay

b) Western Amhara (represented by Addis Zemen, Kola Diba and Zema areas)

Lab No	Field No.	Depth	pH H_2O	pH KCL	EC ds/m	Sand %	Silt %	Clay %	Class
2514/04	KD_S_X		6.7		0.041	18	38	44	Clay
2515/04	KD_M_X		7.5		0.087	26	28	46	Clay
2516/04	KD_M_HM		7.9		0.09	16	34	50	Clay
2517/04	AZ_M_HM		6.3		0.065	26	50	24	Loam
2518/04	AZ_M_X		6.5		0.083	24	36	40	Clay

Lab No.	Field No.	Na	K	Ca	Mg	Sum	CEC Meq/100	Base saturation %	ExC. Al. me/100g
	Meg/100 gm soil								
2514/04	KD_S_X	0.280	0.500	24.200	11.770	36.75	42.40	87	
2515/04	KD_M_X	0.740	1.050	37.350	11.930	51.07	63.92	80	
2516/04	KD_M_HM	0.590	0.680	44.460	9.880	55.61	63.12	88	
2517/04	AZ_M_HM	0.220	0.380	16.430	3.800	20.83	30.00	69	
2518/04	AZ_M_X	0.130	0.920	17.270	11.850	30.17	38.40	79	

Lab No.	Field No.	Total N %	O.C. %	C/N	Av. P. Ol. ppm	Av. K ppm	Fe ppm	Mn ppm	Zn ppm
2514/04	KD_S_X	0.147	1.716	12	3.82				
2515/04	KD_M_X	0.095	1.157	12	22.56				
2516/04	KD_M_HM	0.078	0.878	11	3.34				
2517/04	AZ_M_HM	0.147	1.377	9	4.68				
2518/04	AZ_M_X	0.133	1.516	11	4.64				

Note: KD stands for Kola Diba; AZ for Addis Zemen; S for sorghum; X for nitrogen trial; M for maize; HM for habitat management trial. Soil analysis was conducted at Ethiopia's National Soil Laboratory, Addis Ababa

Appendix 5.3 Mean percent leaf N content at various N fertilizer levels.

Location	Crop type	Soil type	Crop growth stage (leaf sampling)	N fertilizer level (kg/ha)	Mean % leaf N content	SE of N content
Addis Zemen	Maize	Red, clay	Tasseling	0	0.95	0.06
Addis Zemen	Maize	Red, clay	Tasseling	60	0.91	0.06
Addis Zemen	Maize	Red, clay	Tasseling	120	1.12	0.10
Addis Zemen	Maize	Red, clay	Tasseling	180	1.38	0.10
Kola Diba	Maize	Black, clay	Tasseling	0	0.82	0.07
Kola Diba	Maize	Black, clay	Tasseling	60	0.92	0.03
Kola Diba	Maize	Black, clay	Tasseling	120	1.21	0.09
Kola Diba	Maize	Black, clay	Tasseling	180	1.48	0.04
Kola Diba	Sorghum	Red, clay	Flag leaf	0	1.19	0.07
Kola Diba	Sorghum	Red, clay	Flag leaf	41	1.35	0.07
Kola Diba	Sorghum	Red, clay	Flag leaf	64	1.40	0.05
Kola Diba	Sorghum	Red, clay	Flag leaf	87	1.49	0.06

Appendix 5.4 Type 3 tests of fixed effects table, the mixed model procedure, borer density/ plant at various fertilizer and insecticide application levels on sorghum at Kola Diba, western Amhara, 2004.

a) *B. fusca* borers/ plant

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3	31.6	2.38	0.0883
Crop growth stage (GS)	4	1984	139.75	<.0001
Insecticide (I)	1	33.2	26.84	<.0001
N x I	3	37	13.57	<.0001
GS x I	4	1985	70.32	<.0001
N x GS	12	1983	14.91	<.0001

b) Coleopteran borers/ plant

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3	18	0.51	0.6815
Crop growth stage (GS)	4	1838	5.81	0.0001
Insecticide (I)	1	21.2	5.08	0.0348
N x I	3	20.9	1.22	0.3266

c) Earwigs population/ plant

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3	34.3	0.68	0.5702
Crop growth stage (GS)	4	1952	2.45	0.0442
Insecticide (I)	1	40.1	4.34	0.0436
N x I	3	40.5	0.62	0.6050

Appendix 5.5 Type 3 tests of fixed effects table, the mixed model procedure, borer damage at various fertilizer and insecticide application levels on sorghum at Kola Diba, Western Ethiopia, 2004.

a) % Internode damage

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3	25.2	12.8	<.0001
Crop growth stage (GS)	4	2001	284.4	<.0001
Insecticide (I)	1	27.4	181.1	<.0001
N x I	3	32.3	25.6	<.0001

b) % Stem tunnel

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3	25.1	9.9	0.0002
Crop growth stage (GS)	4	2000	205.0	<.0001
Insecticide (I)	1	27.3	125.2	<.0001
N x I	3	32.2	18.3	<.0001

c) Holes/ plant

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3	24.5	17.4	<.0001
Crop growth stage (GS)	4	1996	204.7	<.0001
Insecticide (I)	1	27.7	206.2	<.0001
N x I	3	30.7	23.9	<.0001

Appendix 5.6 Type 3 tests of fixed effects table, the mixed model procedure, yield at various fertilizer and insecticide application levels on sorghum at Kola Diba, Western Ethiopia, 2004.

a) Head weight/ plant

	Num DF	Den DF	F value	P value
N fertilizer (kg/ ha) (N)	3		12.79	<.0001
Insecticide (I)	1		17.67	<.0001
N x I	3		6.45	<.0001

Appendix 5.7 PROC GLM ANOVA table: sorghum and maize grain yield at various fertilizer and insecticide application levels at Kola Diba and Addis Zemen, Western Ethiopia, 2004.

	Num DF	Den DF	F value	P value
Location (L)	1		74.38	<.0001
N fertilizer (kg/ ha) (N)	3		42.75	<.0001
Insecticide (I)	1		6.05	0.0176
N x I	3		1.89	0.3620
L x N x I	7		2.96	0.0115