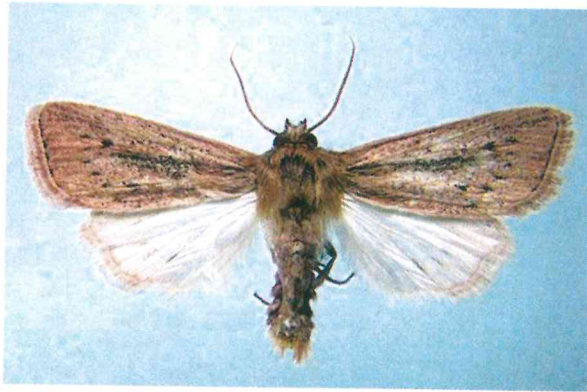


**Roles of Inland Valleys and Maize Cropping
Systems in the Management of Stem Borers and
their Natural Enemies in the Humid Forest of
Cameroon**



vom Fachbereich Gartenbau
der Universität Hannover
zur Erlangung des akademischen Grades eines

Doktors der Gartenbauwissenschaften

- Dr. rer. hort. -

vorgelegte
Dissertation

von

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geboren am 04 November 1962 in Benin

2005

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Dedicate to my late daughter
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Abstract

Roles of Inland Valleys and Maize Cropping Systems in the Management of Stem Borers and their Natural Enemies in the Humid Forest of Cameroon

Adenirin Chabi-Olaye

The present research project aimed at, (i) assessing the role of inland valleys in the invasion of up-land maize fields by both stemborers and their natural enemies, and (ii) investigating the effects of intercropping and soil fertility on the incidence and severity of maize stemborers and on the impact of their natural enemies in the humid-forest zone of Cameroon. For this, surveys and experiments on migration and population dynamics of pests and their natural enemies were conducted in several inland valley and adjacent upland maize fields in three different villages. In field experiments maize monocrops were compared with maize/legume or maize/cassava intercrops in two spatial arrangements, i.e. within row combination and row and strip planting. For investigations on soil fertility, a continuous maize production system was compared with three crop sequence systems, in which maize followed a grain legume (cowpea or soybean), cover crop (mucuna or pigeon) or a bush fallow. Destructive and non-destructive sampling methods were used to assess pest densities, plant damage, maize yield and impact of egg and larval parasitoids in the different cropping systems.

Five different lepidopteran borer species, i.e. *Busseola fusca* Fuller (Noctuidae), *Eldana saccharina* Walker (Pyralidae), *Sesamia* spp. (Noctuidae), *Mussidia nigrivenella* (Ragonot) (Pyralidae), and *Cryptophlebia leucotreta* (Meyrick) (Tortricidae) were commonly found, with *B. fusca* as the most predominant species in all seasons, accounting for about 95 % of total borers species collected. Of 89 inland valley maize fields visited, >90 % were infested by stemborers. The percentage of plant infested ranged from 2-45%. During the dry season, *B. fusca* egg batches were found in 40 % of the fields visited. The average number of plants with eggs was 10%, indicating that moths do fly during the dry season. Flight activity of *B. fusca* was low during the dry season, with approximately 3 trap-catches per week. Egg parasitoids of the *Telenomus* species

complex (Hymenoptera: Scelionidae) were found in about 80 % of the infested fields. In addition, *T. busseolae* Gahan and *T. isis* Polaszek were identified, with *T. isis* being predominant in the inland valleys. These findings suggest that inland valleys maintain carry-over populations of not only *B. fusca* but also of its natural enemies.

Intercropping of maize with non-hosts decreased the number of eggs laid by *B. fusca*, and, depending on the crop association and planting pattern and compared to monocropped maize, it reduced larval and pupal densities by 25-50%. Maize monocrops had 3.0-8.8 times more stems tunnelled and 1.3-3.1 times more cob damage than intercrops. As results, maize yield losses due to stem borers were 1.8-3.0 times higher in mono- than in intercrops. The level of egg parasitism and, with one exception, egg-to adult mortality in *B. fusca*, was not affected. All intercropping systems had the additional advantage that land productivity was higher than with sole maize cropping. The maize-cassava crop was the most efficient in terms of land use and the most productive vis-à-vis sole maize with insecticide application. Intercropping maize with non-host plants did not affect larval parasitism. However, up to twofold higher levels of egg parasitism by *Telenomus* spp. were recorded in inter- compared to monocrops during the short rainy seasons of 2002 and 2003.

Depending on the cover crop species in the rotation, and compared to a continuous maize production system, maize in the rotation systems had 1.5-2 more borers per plant, particularly at the early stages of maize growth. But, at 63 days after planting, larval mortalities were 1.4-1.5 higher in rotation systems than in the continuous maize system. As a result, dead-hearts and tunnel length did not vary significantly among treatments, and grain yield loss due to borers in the continuous cropping system was significantly higher, suggesting that increased nutritional status of the maize plants enhanced both borer fitness and plant vigour, but with a net-benefit for the plant.

The present study provides an increased understanding of the role of inland valleys on the population dynamics of maize stem borers in the humid forest zone of southern Cameroon. Based on the population loads of the borers during the cropping seasons, crop-plant diversity can considerably reduce the build-up of pest populations. In addition, the results of this study show that the integration of grain legumes or cover crops as short fallow improves the supply of mineral N in

the soil and consequently the nutritional status of maize, which reduces its susceptibility to pests. Improving soil fertility can therefore be as very effective means of complementing integrated pest control.

Keywords: Maize Stem Borer, Inland Valley, Intercropping, crop sequence systems, Grain Legume, Cover crop, Grain Yield Loss and Humid forest of Cameroon.

Zusammenfassung

Bedeutung von Feuchtgebieten und unterschiedlichen Maisanbau-systemen in der Bekämpfung von Maisstengelbohrern in Kamerun

Adenirin Chabi-Olaye

Die vorliegende Forschungsarbeit hatte folgende Ziele: (i) Abschätzung der Rolle von Feuchtgebieten (*inland valleys*) für den Befall von höher gelegenen Maisfelder (*upland maize*) durch Stengelbohrer und ihrer natürlichen Gegenspielern, und (ii) Untersuchung der Auswirkungen von Zwischenfruchtanbau (*intercropping*) und Bodenfruchtbarkeit auf die Häufigkeit und Befallsstärke von Maisstengelbohrern und auf die Wirkung ihrer natürlichen Gegenspielern in Regenwaldgebieten Kameruns. Hierzu wurden Erhebungen und Experimente zur Migration und Populationsdynamik der Schädlinge und ihrer Gegenspieler in verschiedenen Feuchtgebieten (*inland valleys*) und angrenzenden Hochland-Maisfeldern dreier Dörfer durchgeführt. In den Feldversuchen wurden Maismonokulturen mit Mais-Leguminosen oder Mais-Maniok-Zwischenfruchtssystemen in zwei räumlichen Anordnungen, d.h. Kombinationen innerhalb von Reihen und Reihen- und Streifen-Pflanzungen, verglichen. Für Untersuchungen zur Bodenfruchtbarkeit wurde ein kontinuierliches Mais-Produktionssystem mit drei Fruchtfolgesystemen, d.h. Mais gefolgt von einer Körnerleguminose (Augenbohne oder Sojabohne), Bodendecker (*Mucuna* oder Straucherbse) oder einer Buschbrache, verglichen. Destruktive und nicht-destruktive Strichprobeentnahmefethoden wurden benutzt um Schädlingsdichten, Schäden an Pflanzen, Maisertrag und den Einfluß von Ei- und Larvenparasitoiden in den verschiedenen Anbausystemen zu ermitteln. Fünf verschiedene Stengelbohrerarten, d.h. *Busseola fusca* Fuller (Noctuidae), *Eldana saccharina* Walker (Pyralidae), *Sesamia* spp. (Noctuidae), *Mussidia nigrivenella* (Ragonot) (Pyralidae), und *Cryptophlebia leucotreta* (Meyrick) (Tortricidae) wurden insgesamt gefunden, wobei *B. fusca* die dominante Art in allen Jahreszeiten war und circa 95% der gesammelten Arten ausmachte. Von den 89 untersuchten Feuchtgebieten (*inland valleys*) waren mehr als 90% von Stengelbohrern besiedelt und 2-45% der Pflanzen waren befallen. Während der Trockenzeit

wurden in 40% der untersuchten Feldern Eigelege von *B. fusca* gefunden. Die durchschnittliche Zahl von Pflanzen mit Stengelbohrereiern betrug 10%, was auf Flugaktivität des Falters während der Trockenperiode hindeutet. Die Flugaktivität von *B. fusca* war während der Trockenperiode mit drei Fängen pro Falle und Woche gering. Eiparasitoide aus dem *Telenomus*-Komplex (Hymenoptera: Scelionidae) wurden in etwa 80% der befallenen Felder gefunden. Die Arten waren *Telenomus busseolae* Gahan und *T. isis* Polaszek, wobei letztere Art dominant in den Feuchtgebieten (*inland valleys*) war. Diese Ergebnisse deuten darauf hin, das in Feuchtgebieten (*inland valleys*) nicht nur überdauernde (*carry-over*) Populationen von *B. fusca* sondern auch von ihren natürlichen Gegenspielern vorkommen.

Mais-Zwischenfruchtanbau mit Nicht-Wirtspflanzen begrenzte die Eiablage von *B. fusca* und reduzierte im Vergleich zu Mais-Monokulturen die Larven- und Puppendichten um 25-50%, in Abhängigkeit von der jeweiligen Zwischenfruchtanbauvariante. Mais-Monokulturen hatten 3.0 bis 8.8 mal mehr Stengelbohrgänge und 1.3-3.1 mal mehr Schäden an Kolben als die Zwischenfruchtanbauvarianten. Monokulturen hatten deshalb im Vergleich zu Zwischenfruchtanbauvarianten 1.8-3.0 mal höhere Verluste durch Stengelbohrer. Die Eiparasitismusrate und teilweise auch die Gesamtmortalität von *B. fusca* wurden nicht beeinflusst. Alle Zwischenfruchtanbausysteme hatten den zusätzlichen Vorteil daß die Produktivität höher war als in den Monokulturen. Die Mais-Maniok-Variante war in der Landnutzung am effektivsten und gegenüber einer Mais-Monokultur mit Insektizidapplikationen auch am produktivsten. Zwischenfruchtanbau mit Nicht-Wirtspflanzen beeinflusste die Parasitierung der Larven nicht. Jedoch wurden in den kurzen Regenperioden 2002 und 2003 doppelt so hohe Parasitierungsraten durch *Telenomus* spp. in den Zwischenfruchtanbauvarianten ermittelt.

Abhängig von der Bodendeckerart in der Fruchtfolge und verglichen mit einem kontinuierlichen Mais-Anbausystem, hatte Mais im Fruchtfolgesystem 1.5-2 mal mehr Stengelbohrer pro Pflanze, insbesondere in den frühen Wachstumsstadien. Aber 63 Tage nach der Pflanzung waren in den Fruchtfolgesystemen die Larvmortalitäten 1.4-1.5 mal höher als im kontinuierlichen Maisanbausystem. Die Anzahl abgestorbener Triebe (*dead-hearts*) und Tunnellängen in den unterschiedlichen Varianten waren deshalb nicht signifikant und

Kornertragverluste durch Stengelbohrer in den kontinuierlichen Anbauvarianten waren signifikant höher, was darauf hindeutet, daß ein verbesserter Ernährungsstatus der Maispflanzen sowohl die Fitness von Stengelbohrern als auch Maispflanzen erhöht, jedoch mit einem Nettogewinn für die Pflanze.

Die vorliegende Studie trägt zu einem verbesserten Verständnis der Bedeutung von Feuchtgebieten für die Populationsdynamik von Maisstengelbohrern in den Regenwäldern von Süd-Kameruns bei. In Abhängigkeit von der Populationshöhe von Stengelbohrern während der Anbauperioden kann die Feldfruchtdiversität den Aufbau von Schädlingspopulationen deutlich reduzieren. Außerdem zeigen die Ergebnisse dieser Arbeit, daß die Einbeziehung von Körnerleguminosen oder Bodendeckern als Kurzbrache die Versorgung des Bodens mit Stickstoff verbessert und somit auch den Ernährungsstatus des Mais, was die Empfindlichkeit der Pflanzen gegenüber Schädlingen deutlich vermindert. Die Verbesserung der Bodenfruchtbarkeit kann daher eine sehr effektive ergänzende Maßnahme zur integrierten Schädlingsbekämpfung sein.

Schlagnvorte: Maisstengelbohrer, Feuchtgebiete, Zwischenfruchtanbau, Fruchtfolgesysteme, Körnerleguminosen, Bodendecker, Kornertragverluste und Regenwaldgebiete Kameruns.

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Abbreviations

ANOVA	Analysis of Variance
CFA	Communauté Française d'Afrique
CMS	Cameroon Maize Series
DAP	Days After Planting
d.f.	Degree freedom
F	Statistical <i>F</i> -value
FAO	Food and Agriculture Organization
Fig.	Figure
GLM	General Linear Model
ICIPE	International Center of Insect Physiology and Ecology
IITA	International Institute of Tropical Agriculture
IPM	Integrated Pest Management
IRAD	Institut de la Recherche Agronomique pour le Développement
IV	Inland Valley
LSD	Least Significant Difference
LSM	Least Square Mean
ns	Not Significant
<i>P</i>	<i>P</i> -value (statistical significance level)
<i>r</i>	Correlation coefficient
<i>r</i> ²	Coefficient of determination in regression
SAS	Statistical Analyses System
SE	Standard Error of the mean
SSA	sub-Saharan Africa
<i>t</i>	Statistical <i>t</i> -value

General Introduction

Maize and cassava are the most important sources for carbohydrates in sub-Saharan Africa (SSA) (FAO, 2001). Both crops were introduced from Latin America by Portuguese traders in the 16th century. In terms of its evolution the maize plant has been considered as the most completely domesticated of all field crops. For centuries its perpetuation has depended entirely upon actions by humans (Martin *et al.*, 1967). During the last decades maize became the most important cereal crop in most regions of Africa and is now a staple for a large proportion of the population. It is grown across all agro-ecological zones, in regions with uni- or bimodal rainfall patterns, allowing for one or two crops a year, respectively.

In Cameroon, maize is an important component of most farming systems and of the diet of many people. It is grown from sea level to the highlands up to 2,000 m a.s.l. After the fall of the cocoa price, maize has become an important source of income for farmers around Yaoundé and Douala, the two largest cities in the humid forest zone of Cameroon (Ndemah and Schulthess, 2002). Generally, as a cash crop maize is monocropped and intercropped with one or several other crops in small scale farming systems (Ndemah, 1999). Maize yields in Cameroon increased between 1993 to 2002 from 1.13 to 2.50 Mg ha⁻¹ (FAOSTAT, 2002), which is still considerably less than the 4.3 Mg ha⁻¹ world-average.

The major biotic constraints for maize production in the forest zone of Cameroon are among others, low soil fertility (Hauser and Nolte, 2002; Hauser *et al.*, 2002) often a result of a short fallow period, and pests and diseases which reduce quality and quantity of pre- and post harvest maize. Among the maize pests, lepidopterous stem and cob borers are the most notorious in SSA. Major species are *Busseola fusca* Fuller (Lepidoptera: Noctuidae), *Eldana saccharina* Walker (Lepidoptera: Pyralidae), *Sesamia calamistis* Hampson (Lep.: Noctuidae) and *Mussidia nigrivenella* Ragonot (Lep.: Pyralidae) (see overview by Polaszek, 1998). In the humid forest of Cameroon, the most frequently reported maize pests are *B. fusca* and *E. saccharina* and to a lesser extent *Sesamia* spp. (Cardwell *et al.*, 1997; Schulthess *et al.*, 1997; Ndemah *et al.*, 2001a; Ndemah *et al.*, 2003). In most borer species, larvae feed on maize plants by tunnelling through the stem

(Fig. 1-1A), thereby causing crop losses ranging from 10-100 % depending on the ecological zone, region and cropping season (Usua, 1968; Leyenaar and Hunter, 1977; Pollet *et al.*, 1978; Bosque-Pérez and Mareck, 1991; Cardwell *et al.*, 1997; Ndemah and Schulthess, 2002).

The life history of all stem and cob borers consists of an egg stage, followed by the larval, pupal and adult stages. However, the development time greatly differs among the species. Within species the duration depends on environmental factors such as temperature, relative humidity and food quality. In *B. fusca* the adults (Fig. 1-1B) generally emerge in the evening and mate. Females lay their eggs between the leaf sheaths of the host plant, and egg batches contain 30-100 eggs (Harris, 1962). On average, a female *B. fusca* lays 400 eggs. The egg incubation period ranges from 5-8 days depending on temperature and relative humidity. The optimum temperature for the development of *B. fusca* lies between 26-30°C (Usua, 1968). In the field, the egg stage lasts 7-11 days (Smithers, 1960). On hatching, the larvae crawl over the plants, congregate in the funnel and commence feeding on the rolled leaves. As the leaves grow away from the funnel, a characteristic pattern of holes or "window panes" can be seen (Harris, 1962). Continuous feeding by the larvae might result in the destruction of the growing point, typically referred to as "dead hearts". After killing a plant, the larvae usually migrate to new plants, enter them by boring into the stem near the base, subsequently followed by tunnelling of the stem and cobs. On average larval development time ranges between 26-33 days.

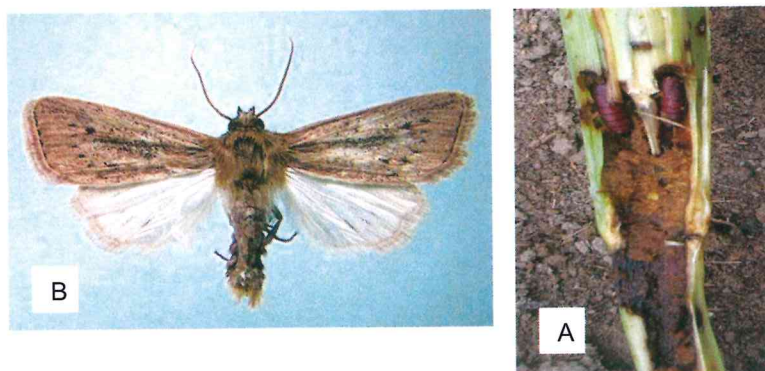


Fig. 1-1. Damage cause by larvae to maize plant (A) and Adult of *Busseola fusca* (B)

During the dry season, the larvae (usually of the third and fourth generation) enter diapause, i.e. a period of arrested development which usually occurs during adverse environmental conditions; larvae may need up to six months to complete their development (Harris, 1962). With the initiation of the rains, the larvae pupate within the stems and 10-12 days after pupation the adult moths finally emerge. Under caged conditions, adult longevity averages 6-7 days (Smithers, 1960). Continuous rearing of non-diapause generations of *B. fusca* can be achieved by feeding the larvae on fresh, green maize (Smithers, 1960; Schulthess and Chabi-Olaye, unpubl. data). This suggests that irrigated maize or maize grown in inland valleys (one of the many forms of hydromorphic soils, typically found along the lower-order streams) will support non-diapause generations during the dry season and thus may constitute a source of infestation of *B. fusca* for maize grown during the first and second rainy season.

Maize is exotic to Africa but except for *Chilo partellus* (Swinhoe) (Lep.: Pyralidae) all stem and cob borers in SSA are indigenous species that probably evolved mostly with native grasses and in the case of *E. saccharina* with sedges (Atkinson, 1980; Schulthess *et al.*, 1997). Studies on the importance of alternative host plants revealed that wild host plants, namely grasses, are highly attractive to ovipositing female moths of stem borers, though survival of immature stages and female fecundity was considerably lower than on maize (Shanower *et al.*, 1993; Sekloka, 1996; Schulthess *et al.*, 1997). Consequently it was proposed that wild host species could act as trap plants (Schulthess *et al.*, 1997) rather than being perceived as a reservoir for pests and thus responsible for severe attack in crop fields as theorized by Bowden (1976). Moreover, surveys in West and Central Africa showed a strongly negative relationship between the abundance of wild grasses in the vicinity of maize fields and borer incidence in the fields (Cardwell *et al.*, 1997; Schulthess *et al.*, 1997). While alternative wild host plants of borers, mainly grasses, are abundant in West Africa, no or few data exist for the humid forest zone of Cameroon where grasses are generally scarce and maize is probably the main host for borers (Ndemah, 1999).

Attempts to control stem and cob borers date back to the early 1900. Despite of considerable research, they are still considered to be the key pre-harvest pests of maize in SSA (see overview by Polaszek, 1998). What are the reasons for the

apparent lack of control, and why are stem and cob borers of such economic importance in SSA?

First, in Africa maize is attacked by a complex of different pest species, often with overlapping spatial and temporal distributions. The relative importance of a given species not only varies with region (East, West), and ecozone, but also between the same ecozone of neighbouring countries. Schulthess *et al.* (1997) argued that this may be due to differences in human population densities. Increasing population pressure and the concomitant expansion of agricultural areas often results in deforestation and displacement of wild habitats of borers, which probably affect the population dynamics of both borers and their natural enemies. This complexity makes breeding for resistance and/or tolerance against stem and cob borers extremely difficult (Bosque-Pérez and Dabrowski, 1989). Thus, despite decades of breeding for resistance, to date no maize variety/line resistant to several important stem and cob borers species is available in Africa.

Second, generally the borer larvae feed internally in the ear and/or the stems of maize plants. For instance, on hatching, larvae of *B. fusca* crawl over the plants, and feed on the rolled leaves. Continuous feeding by the larvae result in the destruction of the growing point, typically referred to as "dead hearts" (Kaufmann 1983). Hence, the larvae and pupae spend most of their lifetime hidden in the stem or cob. This implies for chemical control only a very narrow window of application, i.e. any insecticide has to be sprayed before the larvae have penetrated the stem and/or cob. Moreover, insecticides have to be repeatedly applied to achieve sufficient control levels (Sétamou *et al.*, 2000b; Ndemah, 1999). Yet, use of insecticides is generally beyond the economic means of most subsistence farmers in SSA. Moreover, pesticides are often harmful to the environment and can pose extreme health hazards to the in general poorly trained and equipped users.

The extent of borer-induced yield losses in maize has serious implications on agricultural production in SSA. If African farmers are to increase their net output on the available land and to catch up with the food demands of the increasing rural and urban populations, such crop losses need to be reduced. The control of stem and cob borers is, however, a complex problem, among others because their habit of feeding inside the stems protect them largely against natural enemies and

insecticides. Thus what are promising strategies for control of stem and cob borers?

Most of the research attempts to solve pest problems in SSA maize has focussed on an integrated approach, including host plant resistance (Bosque-Pérez *et al.*, 1997), biological control (Schulthess *et al.*, 1997, 2001; Ndemah *et al.*, 2001a, b), and habitat management technologies based on the management of soil nutrients (Sétamou *et al.*, 1993, 1995; Denké *et al.*, 2000), trap plants (Ndemah *et al.*, 2002) and mixed cropping systems (Schulthess and Ajala, 1999; Ndemah *et al.*, 2003; Schulthess *et al.*, 2004).

Biological control of lepidopterous stem and cob borers has been considered as a major component of integrated pest management (IPM) strategies in Africa (Rao, 1965; Mohyuddin and Greathead, 1970; Mohyuddin *et al.*, 1981; Mohyuddin, 1991; Schulthess *et al.*, 1997; Sétamou, 1999). On Taiwan inundative releases of parasitoids have been tested for control of sugarcane borers (Cheng *et al.*, 1995) and in the USA for maize borers (Wang *et al.*, 1997). However, for economic reasons such an approach would not be feasible in SSA. Hence, most of the research on biological control of stem and cob borers in Africa has focussed on more sustainable techniques. For the indigenous pest species, two approaches are being tested: The first termed 'redistribution' (Rao, 1965), entails searching throughout the entire area of natural distribution of a given pest species, e.g. *B. fusca*, for its natural enemies, especially for parasitoids, that may not occur everywhere. This approach has led to the identification of several promising biocontrol candidates. For instance a Kenyan strain of the braconid larval parasitoid *Cotesia sesamiae* (Cameron) has been introduced and subsequently established in southern Benin (Schulthess, pers. Com.). Moreover, the scarcity of parasitoids of *M. nigrivenella* in Benin suggests ample opportunities for the redistribution approach (Sétamou, 1999). Tritrophic level studies are proposed in regions where *M. nigrivenella* is not a crop pest such as East, Southern and Central Africa in order to identify promising biocontrol candidates. The second approach is termed 'new association', and entails the use of non-coevolved natural enemy species from closely related hosts occupying similar ecological niches (Pimentel, 1963). For example in the exotic stem borer *C. partellus* classical biological control has been successful in East and Southern Africa through the introduction of the braconid parasitoid *Cotesia flavipes* Cameron from Asia

(Overholt *et al.*, 1997). To date most of the research has concentrated on larval parasitoids of stem and cob borers. Less is known on the impact of egg parasitoids, though in some ecologies they are the most important biological control factors (Chabi-Olaye, 1992; Schulthess *et al.*, 1997; Ndemah, 1999). The importance of predators has been postulated by many authors (Mohyuddin and Greathead, 1970; Leslie, 1982; Kfir, 1988; Oloo, 1989; Greathead, 1990), but until today hardly any quantitative data has been published, except for the occasional reference to ants feeding on eggs and first instar larvae of stem borers (Mohyuddin and Greathead, 1970).

Habitat management, i.e. the manipulation of the cultivated and natural environment to preserve the pest-natural enemy balance and the floral and faunal biodiversity, is the second promising technique for management of stem and cob borers in SSA.

Role of wild hosts. For a thorough understanding of the population dynamics and ecology of a given herbivore research should not only be limited to the actual crop but also has to include the ecosystem surrounding the field (Schulthess *et al.*, 1997). For maize monocrops, this implies alternative host plants of stem and cob borers in the vicinity of the maize field, e.g. wild grasses, shrubs and trees (Sétamou, 1999). Because of the relatively short duration of the maize crops in the field, and its susceptibility to borer attacks (maize cannot compensate for stem damage by tillering), biological and/or naturally occurring control of non-diapausing stem borer species has to take place mainly in the wild habitat, exceptions being egg parasitoids which kill the pests before they can cause damage. In addition, those wild host plants not only stabilise the system by serving as a reservoir for natural enemies during the off-season, but many species also act as trap plants, i.e. they are very attractive to ovipositing female moths although they cause mortalities of nearly 100% (Shanower *et al.*, 1993; Schulthess *et al.*, 1997). However, planting wild hosts would very likely not be an adoptable option to farmers (as they are often the same species that also occur as weeds in their maize fields). But, leaving wild habitats intact instead of burning them would increase the stability of the system and help reducing stem and cob borers incidence in maize fields, as shown by survey results from West and Central Africa (Schulthess *et al.*, 1997; Cardwell *et al.*, 1997).

Intercropping with non-hosts. In many regions of SSA, maize is traditionally intercropped with various other crops. Generally intercropping allows farmers a more efficient way of land use, and ensures the availability of food throughout the seasons. There are a number of studies that showed a reduction in stem and cob borer densities when maize is intercropped with legumes or other non-host plants (Adesiyun, 1983; Dissemond and Hindorf, 1990). This may be due to various mechanisms such as the non-host acting as trap plants (Ampong-Nyarko, 1995), increased parasitism (Skovgard and Pats, 1996) as a result of volatiles produced by the non-host (Khan *et al.*, 1997) or increased mortality due to starvation and/or predation (e.g. by ground beetles or other epigaeic predators) of migrating borer larvae from non-hosts to the maize (Kfir, 1995).

Management of soil nutrients. In SSA maize is often intercropped with legumes. Commonly it was believed that farmers would benefit from such an intercropping by increasing the N-content in the soil. In his review paper Stern (1993) examined whether such associations of non-legume and legume crops result in nitrogen benefits for the non-legume plant. Evidence suggests that any nitrogen fixed by e.g. intercropped beans and then transferred to maize is likely to be only a fraction of the full nitrogen requirements of maize, even when conditions for fixation and possible transfer are favorable. However, if the density of intercropped maize is less than that of a monocrop, as it is commonly the case, individual maize plants may benefit by having access to more soil nitrogen (Siame *et al.*, 1997), but again this effect is likely to be small.

Variations in the availability of soil nutrients can influence the susceptibility of plants to pests and diseases (Haseman, 1946). Numerous studies showed the effects of nutrients, such as nitrogen and potassium, on borer incidence in cereals such as rice (Saroja *et al.*, 1987; Thakar and Mishra, 1989; Sharma and Reddy, 1991; MacLean *et al.*, 2003), maize (Archer *et al.*, 1987; Martin *et al.*, 1989; Sétamou *et al.*, 1993, 1995; Sétamou and Schulthess, 1995; Ndemah, 1999; Denké *et al.*, 2000) and sugar cane (Atkinson and Nuss, 1989). In most of the experiments, mineral fertilizer was used. However, MacLean *et al.* (2003) showed that mulch from leguminous multipurpose trees, planted as hedgerows, increased attack of rice seedlings by stem borers such as *S. inferens* (Walker). Short-duration fallows with grain legumes and cover crops such as *Mucuna pruriens* (L.) DC. varieties, *Pueraria phaseoloides* (Roxb.), *Cajanus cajan* (L.) Millsp. and

Canavalia ensiformis (L.) DC. have shown to considerably increase succeeding maize yields (Balasubramanian and Nguimgo, 1993; Horst and Härdter, 1994; Ile *et al.*, 1996; Carsky *et al.*, 1998). Maize grain yields of $> 4 \text{ Mg ha}^{-1}$ were obtained in southern Cameroon after a short-term fallow with mucuna (Hauser and Nolte, 2002). Consequently, there is a tremendous potential for farmers in West and Central Africa to integrate leguminous cover crops into their cropping patterns. However, no information is available on the short-term effects of cover crops or grain legumes on maize pests.

The present research project shall be a contribution to a comprehensive pest control program for maize stem and cob borers already under way in many countries of Africa, and seeks to develop a systems-based plant protection strategy, which can respond to pest-related production constraints in maize farming systems, particularly in the humid forest zone of Cameroon. Emphasis is given to lepidopteran maize stemborers, with particular reference to *B. fusca* and its natural enemies. Major objectives are an assessment of how intercropping and/or increased soil fertility proprieties can reduce stem and cob borer damage and increase yields of maize, as well as the elucidation of underlying control mechanisms with particular emphasis on the role of natural enemies such as egg and larval parasitoids. A second objective is the assessment of the role of inland valleys, which are often planted with maize during the off-season (i.e. dry season), as reservoirs for both pests and beneficials (mainly egg parasitoids) and, thereby, their role in the invasion of up-land maize fields by borers and their parasitoids during the growing seasons.

In the following chapter (chapter 2) the role of inland valleys in the invasion of up-land maize fields by borers and their parasitoids during the growing seasons are presented and the implications for biological control of stem borers in the humid forest zone of Cameroon are discussed. Studies on the impact of intercropping on stem borers, yield losses, as well as land-use efficiency are described in chapters 3 and 4. Chapter 5 describes the effect of crop sequences with leguminous food or cover crops on *B. fusca* incidence and maize yields. The general discussion is presented in chapter 6.

The Role of Inland Valleys in the Invasion of Upland Maize Fields by Stem Borers and their Natural Enemies in the Humid Forest Zone of Cameroon

Abstract

During the dry season in the humid forest zone of Cameroon, maize is the most important dry season cash crop grown in hydromorphic inland valleys. Such dry-season fields, however, may also be reservoirs for pests such as the stem borer *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and its natural enemies, which invade adjacent upland fields during the rainy season. Pest and parasitoids were monitored in inland valleys and close-by upland maize fields from January 2002 through December 2004. Each year, surveys started during the dry season in the inland valleys and were extended to the upland maize fields during the first and second cropping season. In addition, the flight activity of *B. fusca* was monitored with pheromone traps in six inland valleys from mid December 2003 until end of May 2004. Trap catches and oviposition data showed that *B. fusca* was active throughout the dry, long and short rainy seasons of 2004. Egg batch densities were considerably lower in the dry than in the rainy seasons. The most important natural enemies were the scelionid egg parasitoids *Telenomus busseolae* Gahan and *T. isis* Polaszek, with *T. busseolae* more abundant in the long and short rainy seasons in the upland fields and *T. isis* as the predominant species in the dry season in the inland valley fields. *B. fusca* was the predominant borer species in all seasons in maize in inland valleys as well as in upland fields, followed by *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *B. fusca* larval densities were lowest in the inland valleys and then increased in the course of the year in the upland fields. By contrast, *S. calamistis* densities were higher in inland valleys than in upland maize fields. At harvest of the inland valley maize, *B. fusca* and *E. saccharina* larval densities were 47.3 and 15.5 times, respectively, higher than on old maize stubbles in up-land fields planted during the previous year. Percentages of stem tunneling and cob damage were 3 to 15 times higher in the long and short rainy

seasons than in the dry season. As a result, grain yields as well as the marketable cob index were 1.1 to 2 times higher in the dry season than in the long and short rainy seasons, indicating the importance of inland valleys for dry-season maize production in the humid forest zone of Cameroon. These findings show that inland valleys are reservoirs for borers and their natural enemies, which invade upland maize fields during the cropping season.

Introduction

In sub-Saharan Africa (SSA), inland valleys (IVs) constitute agro-ecosystems with a high potential for food production (Kilian, 1972; Andriessse and Fresco, 1991; Izac *et al.*, 1991; Windmeijer and Andriessse, 1993; Thenkabail and Nolte, 1995 & 1996). They are one of many forms of spatio-temporal moisture gradient lands that are characterized by hydromorphic soils and are typically found along lower-order streams (Fig. 2-1). The degree of cultivation of IVs depends, among others, on road-networks, population densities, availability of low-input technologies, and socio-economic factors (Thenkabail and Nolte, 1995 & 1996).

Maize is the most important crop in IVs of southern Cameroon, notably in the vicinity of major towns, because it serves as an important dry-season cash crop (Ndemah, 1999). Maize is cropped in IVs from early January to April. Many bottomlands of these valleys stay moist within the rooting zone during the dry season, allowing for the cultivation of a non-irrigated crop during the dry season. Therefore, crops in IVs often grow concurrently with first season upland maize, which is sown in southern Cameroon from mid-March until mid-April.

In SSA, maize is attacked by a complex of stem and cob borer species belonging to the families of Noctuidae, Pyralidae and Crambidae (see overview by Polaszek, 1998). Common borer species in the humid forest zones of Cameroon include *Busseola fusca* Fuller (Lepidoptera: Noctuidae), which is the most widely distributed and abundant species, and *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Cardwell *et al.*, 1997; Schulthess *et al.*, 1997; Ndemah *et al.*, 2001a; Ndemah *et al.*, 2003). Generally, the predominance of maize stem borer species and their incidence varies with season (Schulthess *et al.*, 1997) and yield losses range from 10-100 % depending on the season (Cardwell *et al.*, 1997; Ndemah *et al.*, 2001; Ndemah and Schulthess, 2002).

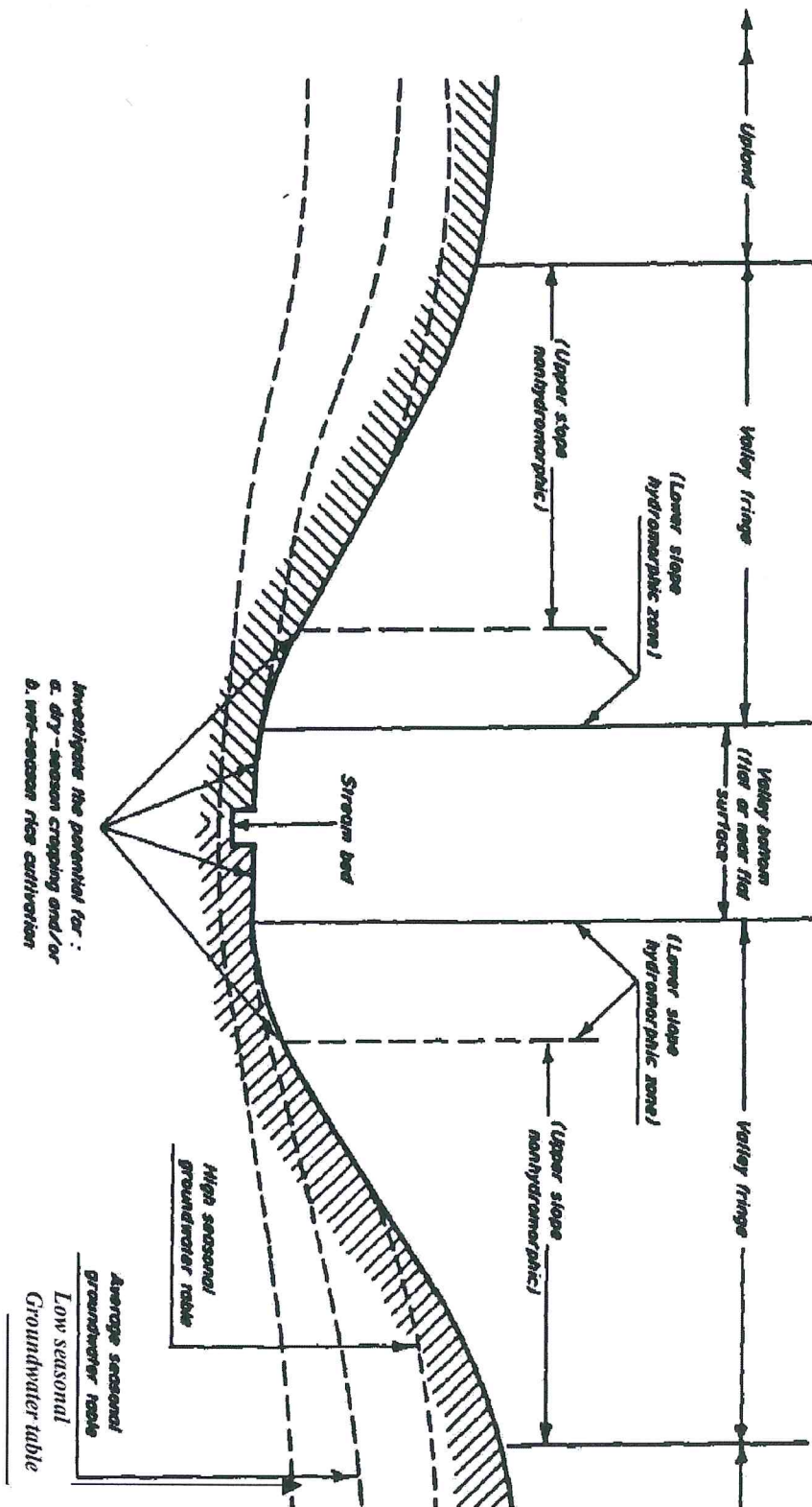


Fig. 2-1. Cross-section showing a model inland valley as defined by Thenkabail and Nolte (1995 & 1996).

In upland maize, *B. fusca* larvae enter their diapause at the onset of the dry season. Thus during this period eggs are not available to egg parasitoids like *Telenomus* spp. (Hymenoptera: Scelionidae), which are the most important parasitoids of noctuid stem borers in western Africa (Schulthess *et al.*, 2001; Ndemah *et al.*, 2003). Moreover, the host finding ability of larval parasitoids, which often need fresh frass to locate their hosts (Mohyuddin, 1971; Hailemichael *et al.*, 1997), may be severely hampered. Consequently parasitoids may become locally extinct during the dry season in upland maize as hypothesized by Ndemah *et al.* (2001). In previous surveys, high levels of infestations by *B. fusca* were found in IV maize (F. Schulthess, ICIPE, pers. com.). However, it is not known whether these were due to non-diapausing *B. fusca* or whether in IV maize the diapause is broken earlier. It is hypothesized that IVs play an important role in the population dynamics of stem borers in general and that of *B. fusca* and its associated natural enemies in particular. IVs could serve as a reservoir during the dry season from which adjacent upland fields are invaded. It is further hypothesized that IVs harbour non-diapausing noctuid borer species such as *Sesamia* spp. which, can serve as alternative hosts of parasitoids of *B. fusca* during the dry season.

The present study therefore attempts to elucidate the role of IVs in the invasion of upland maize fields by stem borers and their natural enemies in the humid forest zone of southern Cameroon.

Materials and Methods

Experimental site

This study was carried out in the forest margins benchmark area in southern Cameroon (Fig. 2-2). The benchmark was established on the basis of a resource management survey, conducted by the International Institute of Tropical Agriculture (IITA) and the Institute of Agronomic Research for Development (IRAD) (Gockowski *et al.* 1998). The village benchmark sites for this work is from the Mbalmayo block, characterized by the Mesophilus humid tropical forest land use category (Millington *et al.*, 1994). Three villages were surveyed, i.e., Akometam, Awae and Mvoutessi (Fig. 2-2).

The area is characterized by a bimodal distribution of rainfall, with an annual precipitation of about 1,500 mm and peaks in June and September. The first and

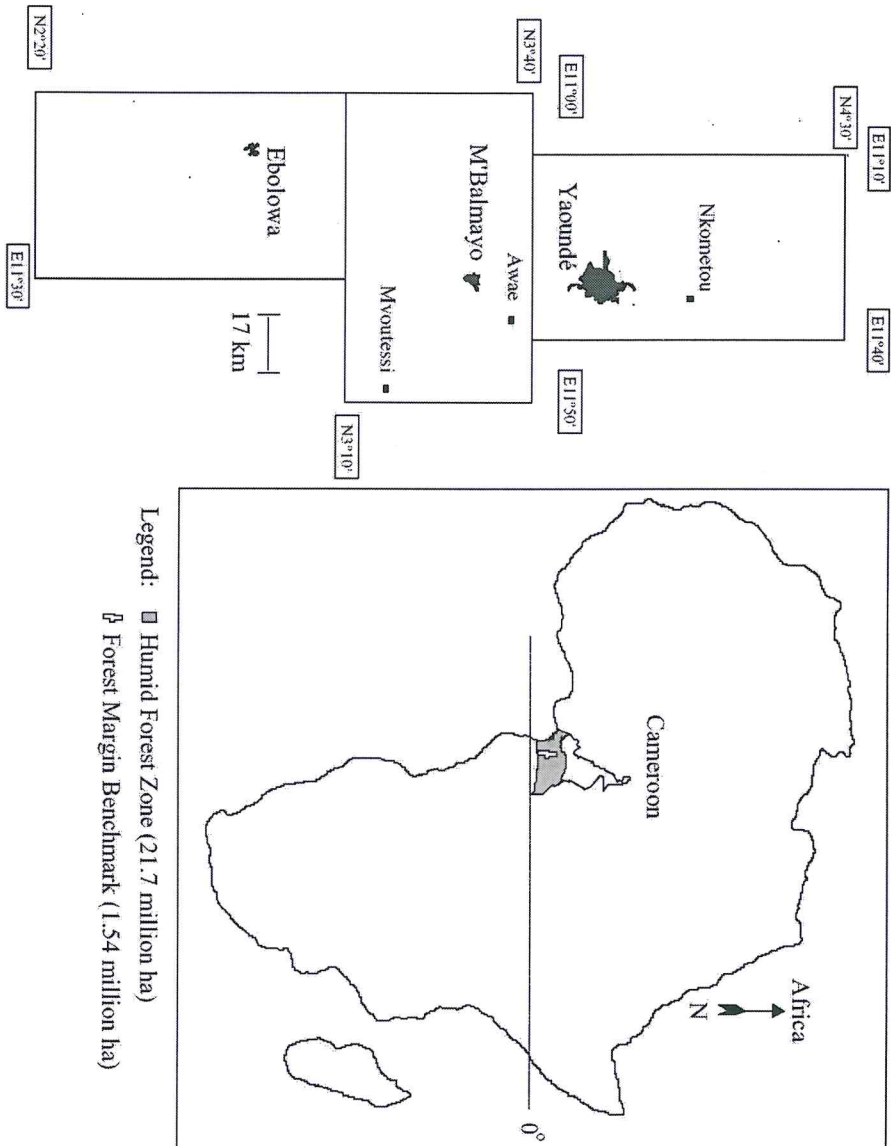


Fig. 2-2. Study area and sampling villages.

second growing seasons, hereafter referred to as long and short rainy seasons, respectively, last from mid March to mid July, and from mid August to end of November, respectively. A short dry spell of about four weeks occurs in July. The major dry season starts in the third week of November and lasts until beginning of March.

General procedure

Maize fields were surveyed during the dry, long and short rainy seasons from 2002 to 2004. Surveys started in the IVs during the dry season and were extended to the upland fields during the two cropping seasons. In 2004, surveys were restricted to two villages, i.e., Awae and Akometam.

During the dry seasons, depending on the availability of maize, 10-12 IV maize fields were investigated per village. The valleys were at 300-500 m distance of each other. Each field was visited three times, i.e., at vegetative stage, tasseling and at harvest. At the end of the dry season, beginning of the first cropping season. Around each IV surveyed during the dry season 1-2 upland maize fields were selected at random at up to 100 m distance from the valley. Similarly, each upland field was visited three times during a cropping season. Field sizes were on an average 0.075 and 0.18 ha in the IV and upland, respectively.

Surveys in the vegetative stage of maize. During the vegetative growth stage, surveys were carried out when maize plants had between 4-8 leaves, with the exception of the long rainy season of 2002 (02LR), during which the survey was done shortly before tasseling. (In that particular season, most fields were planted earlier than planned with the farmers). On each sampling occasion, 100 maize plants were randomly inspected non-destructively for stem borer egg batches. The batches were brought to the laboratory for egg counts. Each batch was kept individually in a plastic container at $27 \pm 1^\circ\text{C}$ and $70 \pm 5\%$ relative humidity for about one month, after which all borer larvae or adult parasitoids had emerged. Larvae hatching from partly parasitized egg batches were reared on pieces of maize cobs to determine the borer species. Obviously parasitized but not hatched eggs were dissected for determination of parasitoid species. Parasitoids were identified to species level using the identification key by Polaszek *et al.* (1993).

Two kinds of parasitization rates were calculated for each species: a) mean egg parasitism per field calculated as percentage of eggs parasitized within an individual egg batch, averaged over all egg batches found in a field; b) the percentage of egg batches per field with parasitoids - this was referred to as 'discovery' efficiency by Bin and Vinson (1991) and provides information on the searching ability of a parasitoid. In addition, the percent of discovered egg batches that yielded both *Telenomus busseolae* Gahan and *T. isis* Polaszek (both Hymenoptera: Scelionidae) (herewith referred to as 'mixed') and percentage of plant with eggs were calculated.

Surveys in the reproductive stage of maize. Maize plants were destructively sampled at tasseling and at harvest (between soft dough and grain maturity, respectively). At each sampling date, fields were divided into four quadrants and six maize plants were randomly taken per quadrant. Plant height, number of borers, and plant damage variables (i.e., number of nodes and internodes bored, tunnel length in cm) were recorded per plant. Larval and pupal parasitism was assessed on a per field basis only and for each borer species separately. To this end, live larvae were held singly in a vial (10.3 cm length and 4.5 cm diameter) provided with young succulent stems or cob pieces of maize. Larvae were reared until pupation or parasitoid emergence. Parasitoids emerging from borer larvae and pupae were counted according to species and preserved in 70 % alcohol for identification by the taxonomists at the Insect Museum of IITA in Cotonou, Benin. At harvest, the same data as described above were collected and in addition cob damage by borers, estimated as the percentage of grains consumed, was determined. Cobs were removed, dehusked and weighed. The number of marketable fresh cobs was determined by the farmers, based on the cob size and percentage of grains damaged by borers. For determining dry matter yields, a sub-sample of eight cobs per field was dehusked, weighed, dried and the dry grains removed and weighed again to determine grain dry matter yield.

Seasonal abundance of B. fusca and their natural enemies in the inland valleys

Depending on vegetation, soil type, and availability of water in the lower part of the valley fringe, six IVs were selected together with farmers at Awae in the dry

season of 2004. A maize field was established in each valley and a pheromone trap (for details of the trap see below) was deployed and positioned approximately 50-75 m apart from each valley to monitor the flight activity of *B. fusca*. Trial plots were cleared in mid December and maize was planted between 5-7 January, at 75 cm between rows and 50 cm within rows. The field size was 12 m x 12 m. Four seeds of 110-days open pollinated maize cv. Cameroon Maize Series (CMS) 8704 were sown per hill and the stands thinned to two plants per hill 14 days after planting (DAP). Fields were manually kept weeds free.

During the vegetative stage of maize, 100 IV maize plants and 200 grass tillers around the valleys were inspected weekly for stem borer egg batches from 21 until 77 DAP in each IV field. Investigations of maize stubbles in upland fields planted during the previous season adjacent to the IVs were carried out between mid January until April 2004. Forty maize stubbles were destructively sampled per month. Borer larvae and pupae were recorded per plant. At harvest of the IV maize, larval densities were assessed from 40 maize stubbles, 100 grasses and 24 plants per field.

To monitor the flight activity of *B. fusca*, six wire-mesh delta-traps were constructed. Each trap was 26 cm long, 9.5 cm wide and 13 cm height. Sticky floors coated with a layer of polybutene were used. Lure dispensers were suspended by a wire 2 cm above the sticky floor inside the metal trap. Traps were mounted 1.5 m above the ground on a metal conduit pipe (2 cm diameter). The slow-release formulation pheromone lures (Biobest Ltd., Westerlo, Belgium) were composed of a mixture of (Z)-11-Tetradecenyl acetate, (E)-11-Tetradecenyl acetate and (Z)-9-Tetradecenyl acetate in a ratio of 10:2:2 (Hall *et al.*, 1981). The six traps were inspected weekly from mid December 2003 till end of May 2004. Sticky floors were replaced after about three weeks. The number of moths caught per week was recorded. The pheromone lures were replaced in all traps once every 3-4 weeks. In addition, rainfall data was collected from IITA village station every month.

Statistical Analysis

The variation in *B. fusca* egg and larva densities, discovery efficiency, eggs parasitism, plant growth, damage variables and yield parameters were analysed

by ANOVA, using the mixed model procedure of SAS (SAS, 1997). Season was a fixed effect and field and village were random effects. Least squares means (LSM) were separated using the t-test. The significance level was set at $P = 0.05$. Correlation and regression analyses were computed to assess interactions between the different variable components of the system.

Marketable Cob Index (MCI). Twenty-four plants were sampled per field at harvest and the total number of cobs harvested. The number of marketable cobs were determined using a zero to three rating scale, i.e., marketable cob index of 0 = cob not marketable (worth 0 Franc CFA); 1 = low market value (50 Franc CFA); 2 = good market value (75 Franc CFA); 3 = high market value (100 Franc CFA). The marketable ear index (MCI) was calculated as follows:

$$MCI = (\sum Si \cdot Ni) / c$$

where, c was the total number of cobs harvested on the 24 plants sampled, Si the rating scale and Ni the number of cobs having the rating Si ($i = 0, 1, 2, \text{ or } 3$).

Results

Seasonal and regional variation in abundance of stem borers and their natural enemies.

Egg infestation and parasitism. For a given village, egg batch density increased significantly from the dry to the first and second seasons except for the long and short rainy seasons of 2003, which had similar egg batch densities (Fig. 2-3). In 2002, discovery efficiency increased with season and peaked in the short rainy season. It then decreased and reached a low in the long rainy season of 2003. A second peak was observed in the dry season of 2004. It decreased again until the short rainy season of 2004. Overall, the seasonal fluctuation of egg batches and parasitism showed the same pattern in each village, and egg batch densities and the discovery efficiency did not significantly vary among villages ($F = 1.40$, $df = 2$, $P = 0.248$ for egg batch and $F = 0.49$, $P = 0.614$ for discovery efficiency (data pooled across years)). Therefore, number of egg batches, % plants with eggs, number of larvae per plant as well as parasitism were presented per year/season.

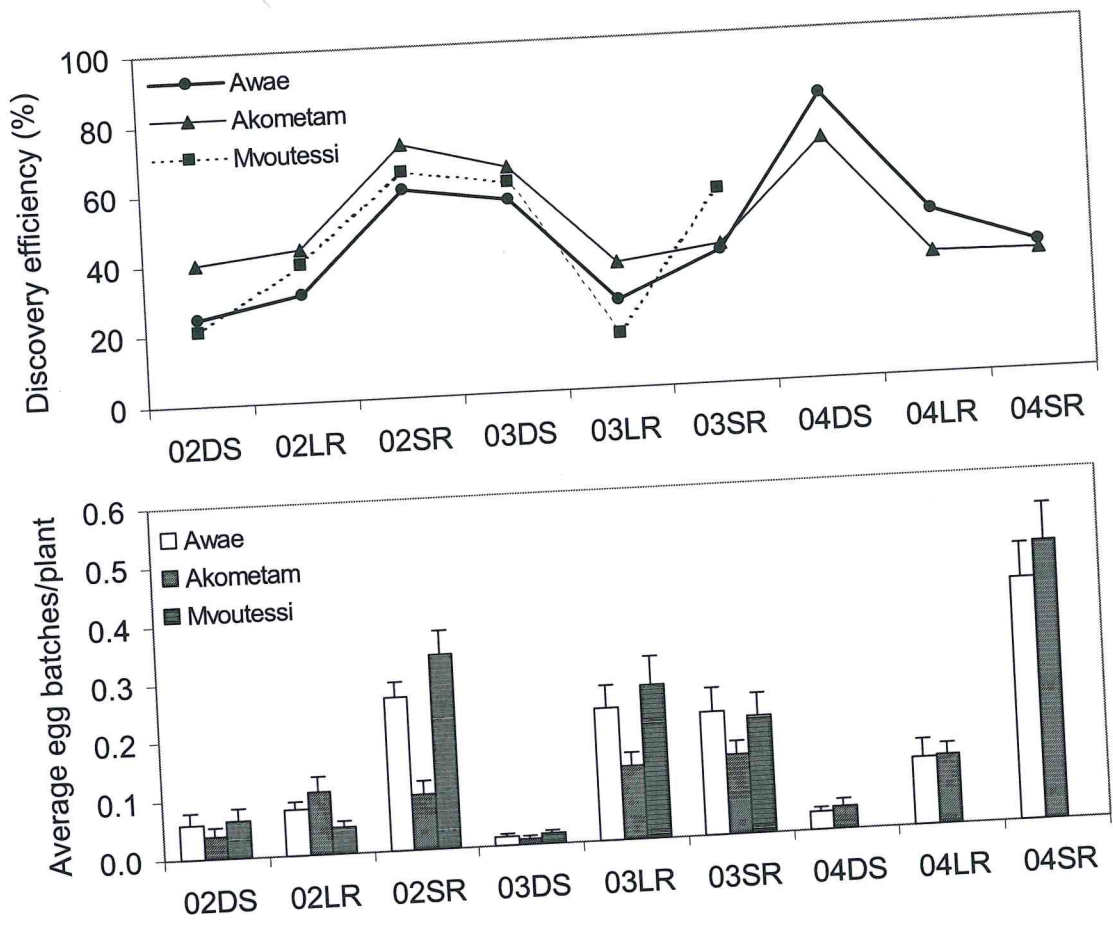


Fig. 2-3. Temporal dynamics of stem borers and their natural enemies in three sampling villages. Horizontal axis represents year and season, e.g., 02DS represents the dry season of 2002 and LR & SR represent the long and short rainy season, respectively.

No differences in batch size were found between seasons ($F = 2.05$, $df = 8$, $P = 0.244$) and the average number of eggs per batch ranged from 14.2-19.7 (Table 2.1).

In 2002, the average number of egg batches per plant did not significantly differ between the dry and long rainy seasons, and it was 4.2 times lower in the dry than in the short rainy seasons (Table 2.1). In 2003, no difference in egg batch density was found between the long and the short rainy seasons, and the averages were 18-20 times higher compared to the dry season. In 2004, the lowest egg batch density was found in the dry season and it was 3 and 11 times lower than in the long and short seasons, respectively (Table 2.1).

The percentage of plants with stem borer eggs followed the same pattern as that of egg batch density but it did not significantly differ between the dry and long rainy seasons of 2004 (Table 2.1).

In 2002, a total of 1,115, 1,937 and 1,589 egg batches were collected in the dry, long and short rainy seasons, respectively. Of the total egg batches collected in the dry season 55.1 % of the eggs in the sub-samples stemmed from *B. fusca*, the remaining were *Sesamia* spp. (Table 2.1). During the long and short rainy seasons of 2002, the percentage of *B. fusca* in the sub-samples increased and was 1.6-1.8 times higher in the upland as compared to the IV fields. In 2003 and 2004, the percentage of *B. fusca* in the sub-samples was 1.3-1.4 times higher in the upland than in the IV fields (Table 2.1).

Telenomus busseolae and *T. isis* were the only parasitoids attacking stem borer eggs both in upland and IV fields. The discovery efficiency significantly varied with season (Table 2.1). In 2002, discovery efficiency did not significantly differ between the dry and long rainy seasons, and it was 1.7-2.4 times lower than in the short rainy season (Table 2.1). The average discovery efficiency was 2.3 and 1.3 times higher in the dry than in the long and short rainy seasons of 2003, respectively. In 2004, the mean discovery efficiency did not significantly differ among the long and short rainy seasons, but it was 2 times lower than in the dry season. The percentage of egg parasitism varied between seasons and followed the same trends as that of the discovery efficiency (Table 2.1). However, the mean percentage of egg parasitism did not significantly differ between the dry and short rainy seasons. *T. busseolae* was abundant in the long and short rainy seasons while *T. isis* was predominant in the dry season (Table 2.1). The percentage of

Table 2.1. Average (\pm SE) oviposition, egg infestation (%) and parasitism of maize stem borers, during the dry, long and short rainy season (DS, LR and SR respectively) of 2002, 2003 and 2004.

Year/ Season	Oviposition and infestation				Parasitism and species composition					
	Eggs per batch	Egg batch per plant	% plant with eggs	<i>Busseola</i> <i>fusca</i> (%) ¹	Discovery Efficiency ²	Average	Egg parasitism (%) Relative importance			
							<i>Telenomus</i> <i>busseolae</i>	<i>Telenomus</i> <i>isis</i>	Mixed ³	
2002										
DS	19.7 \pm 2.7	0.06 \pm 0.03b	8.5 \pm 2.3b	55.1	27.3 \pm 7.3b	25.4 \pm 5.6b	32.7	67.3	59.7	
LR	17.3 \pm 1.0	0.07 \pm 0.02b	10.1 \pm 1.8b	90.2	38.3 \pm 4.8b	30.3 \pm 3.3b	78.4	21.6	11.9	
SR	16.3 \pm 0.9	0.25 \pm 0.02a	21.4 \pm 1.7a	98.5	65.2 \pm 4.3a	45.4 \pm 1.6a	58.1	41.9	33.3	
2003										
DS	14.2 \pm 1.3	0.01 \pm 0.02b	2.3 \pm 1.4b	70.5	58.6 \pm 5.6a	42.1 \pm 7.2a	38.2	61.8	50.6	
LR	17.2 \pm 0.6	0.20 \pm 0.02a	16.1 \pm 1.3a	96.5	25.8 \pm 3.5c	20.0 \pm 1.4b	70.0	30.3	19.8	
SR	15.6 \pm 0.4	0.18 \pm 0.02a	14.5 \pm 1.3a	98.8	44.4 \pm 3.4b	35.6 \pm 1.4a	68.2	31.8	20.5	
2004										
DS	16.7 \pm 1.7	0.04 \pm 0.03c	7.6 \pm 2.3b	75.8	75.5 \pm 7.1a	54.2 \pm 9.8a	37.3	62.7	41.7	
LR	19.0 \pm 0.5	0.12 \pm 0.02b	10.2 \pm 1.5b	97.8	40.5 \pm 4.1b	26.6 \pm 2.0b	69.6	30.4	12.4	
SR	16.8 \pm 0.4	0.45 \pm 0.03a	33.8 \pm 2.2a	98.4	34.9 \pm 5.5b	30.8 \pm 1.5b	54.6	45.4	30.0	

Notes: ¹, the percentage of stem borer eggs stemming from *B. fusca*; ², the percentage of egg batches per field with parasitoids; ³, the percentage of egg batches having both *T. busseolae* and *T. isis*. Within column for a given year, means followed by the same letter are not significantly different at $P < 0.05$ (t-test).

egg batches harbouring both *T. busseolae* and *T. isis*, was 1.4-5 times higher in the dry than in the long and short rainy seasons (Table 2.1).

Larval abundance and parasitism. The percentage of plants infested by borer larvae varied with seasons (Table 2.2). In 2002, the highest % plants infested was found in the long rainy season and it was 3 and 1.3 times higher than in the dry and short rainy seasons, respectively. In 2003, % plants infested did not significantly differ among the long and short rainy seasons, and it was 4 times higher than in the dry season (Table 2.2). The highest % plants infested was found in the short rainy season of 2004 and it was 4.6 and 1.9 times higher than in the dry and long rainy seasons, respectively.

Of the total stem borer larvae collected, *B. fusca* was the predominant species in all seasons and locations (Table 2.2). The number of *B. fusca* larvae per plant varied with seasons and followed the same pattern as that of % plants infested (Table 2.2). *Eldana saccharina* was the second most important borer species; the highest number was found in the short rainy season of 2002 and it was 10.3 and 1.9 times higher than in the dry and long rainy seasons, respectively. In 2003, it did not significantly differ between the long and short rainy seasons, and it was 3-4.6 times higher than in the dry season. In 2004, no differences in larvae were found between the dry and long rainy seasons and densities were, respectively, 6 and 15 times higher than in the short rainy season. In general, densities of *Sesamia* spp. larvae were 2.6 and 4.2 times higher in the dry season than in the long and short rainy seasons, respectively (Table 2.2). Densities of the cob-boring *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) and *Cryptophlebia leucotreta* Meyrick (Lepidoptera: Tortricidae) did not significantly differ between seasons, and the average number of larvae per plant ranged between 0.01-0.04 (Table 2.2).

The percentage of larval parasitism did not vary significantly between seasons ($P > 0.05$) and the average per field ranged between 4.4-9.1 %. The most common larval parasitoid species were *Actia* sp. (Diptera: Tachinidae), accounting for > 89 % of all larval parasitoids, and the two braconids *Dolichogenidea polaszeki* Walker and *Cotesia* sp.

Table 2.2. Average (\pm SE) plant infested (%), and maize stem borers larvae per plant, during the dry, long and short rainy season (DS, LR and SR respectively) of 2002, 2003 and 2004

Seasons	% Plant infested				<i>Busseola fusca</i>				<i>Sesamia</i> spp.			
	2002	2003	2004	2004	2002	2003	2004	2004	2002	2003	2004	2004
DS	18.5 \pm 4.4c	10.9 \pm 2.7b	15.6 \pm 5.1c	0.30 \pm 0.41c	0.46 \pm 0.19b	0.42 \pm 0.44c	0.14 \pm 0.02a	0.07 \pm 0.01a	0.08 \pm 0.01a			
LR	56.1 \pm 3.2a	42.1 \pm 2.2a	38.7 \pm 2.8b	3.86 \pm 0.32a	1.65 \pm 0.15a	2.32 \pm 0.30b	0.02 \pm 0.02b	0.04 \pm 0.01a	0.05 \pm 0.02b			
SR	44.2 \pm 2.4b	43.4 \pm 2.0a	72.3 \pm 4.8a	1.53 \pm 0.22b	1.59 \pm 0.14a	4.17 \pm 0.42a	0.03 \pm 0.01b	0.01 \pm 0.01b	0.03 \pm 0.02b			
	<i>Eidana saccharina</i>				<i>Mussidia nigrivenella</i>				<i>Cryptophlebia leucotreta</i>			
	2002	2003	2004	2004	2002	2003	2004	2004	2002	2003	2004	2004
DS	0.03 \pm 0.14b	0.05 \pm 0.02b	0.06 \pm 0.04a	0.01 \pm 0.03	0.02 \pm 0.01	0.02 \pm 0.01	0.01 \pm 0.02	0.02 \pm 0.01	0.01 \pm 0.01	0.01 \pm 0.01	0.01 \pm 0.01	0.01 \pm 0.01
LR	0.16 \pm 0.11a	0.23 \pm 0.04a	0.15 \pm 0.03a	0.03 \pm 0.02	0.03 \pm 0.01	0.01 \pm 0.01	0.03 \pm 0.01	0.01 \pm 0.01	0.03 \pm 0.01	0.01 \pm 0.01	0.03 \pm 0.01	0.03 \pm 0.01
SR	0.31 \pm 0.07a	0.15 \pm 0.04a	0.01 \pm 0.04b	0.04 \pm 0.02	0.01 \pm 0.01	0.01 \pm 0.01	0.02 \pm 0.01	0.01 \pm 0.01	0.02 \pm 0.01	0.01 \pm 0.01	0.01 \pm 0.01	0.01 \pm 0.01

Notes: Within column for a given variable, means followed by the same letter are not significantly different at $P < 0.05$ (t-test).

Trap catches of B. fusca in IVs in relation to rainfall, field infestation and parasitism

During the 2003/04 dry season, precipitations (Fig. 2-4A) was lowest in January and highest in April. The flight activity of *B. fusca* began in December 2003, with trap catches of one moth per week. It then increased to nearly five moths in early February and decreased to two trap catches per week in the second and third week of March. Thereafter, it increased again up to six moths per trap and week in early April and levelled off to three to four moths in May (Fig. 2-4A).

During the dry season of 2004, egg batches were collected from 21 up to 77 DAP on both maize and wild grasses surrounding the IVs maize fields (Fig. 2-4B). In total 105 egg batches were collected, of which 82.1 % stemmed from *B. fusca*. Egg batches collected per grass tiller did not significantly differ among DAP ($F = 2.1$, $df = 7$, $P = 0.100$) and the mean density across DAP was 0.007 per tiller (Fig. 2-4B). By contrast, egg batch density on maize plants significantly varied with DAP ($F = 26.17$, $df = 7$, $P < 0.001$) and it was on average 6.8 times higher than on grasses. The average number of egg batches per maize plant was 0.014 at 21 DAP. It increased to 0.17 at 42 DAP and decreased to 0.007 at 77 DAP (Fig. 2-4B).

The discovery efficiency on grasses was 25 % between 21-28 DAP, decreased at 42 DAP and levelled off to about 30 % per field between 49 and 63 DAP (Fig. 2-4B). On maize, discovery efficiency varied significantly with DAP ($F = 2.66$, $df = 7$, $P = 0.024$). It was 26.7 % at 21 DAP, increased to 83.1 % at 49 DAP and decreased to 37.5 % at 63 and 77 DAP.

Adult catches of *B. fusca* per week were significantly positively related to rainfall, while no relationship was found between rainfall and number of egg batches as well as level of parasitism (Table 2.3). By contrast, egg batches collected on maize and grasses were significantly positively related to adult catches (Table 2.3). There was a positive relationship between egg batches collected on maize and those collected on grasses as well as between their levels of parasitism (Table 2.3).

Busseola fusca, *Sesamia* sp. and *E. saccharina* larvae were also found during the dry season in old maize stubbles of upland fields planted in the preceding year (Table 2.4). In January, the average number of diapausing larvae of *B. fusca* was 0.54 per plant. It then decreased and was 7.7 times lower in March. Larvae of

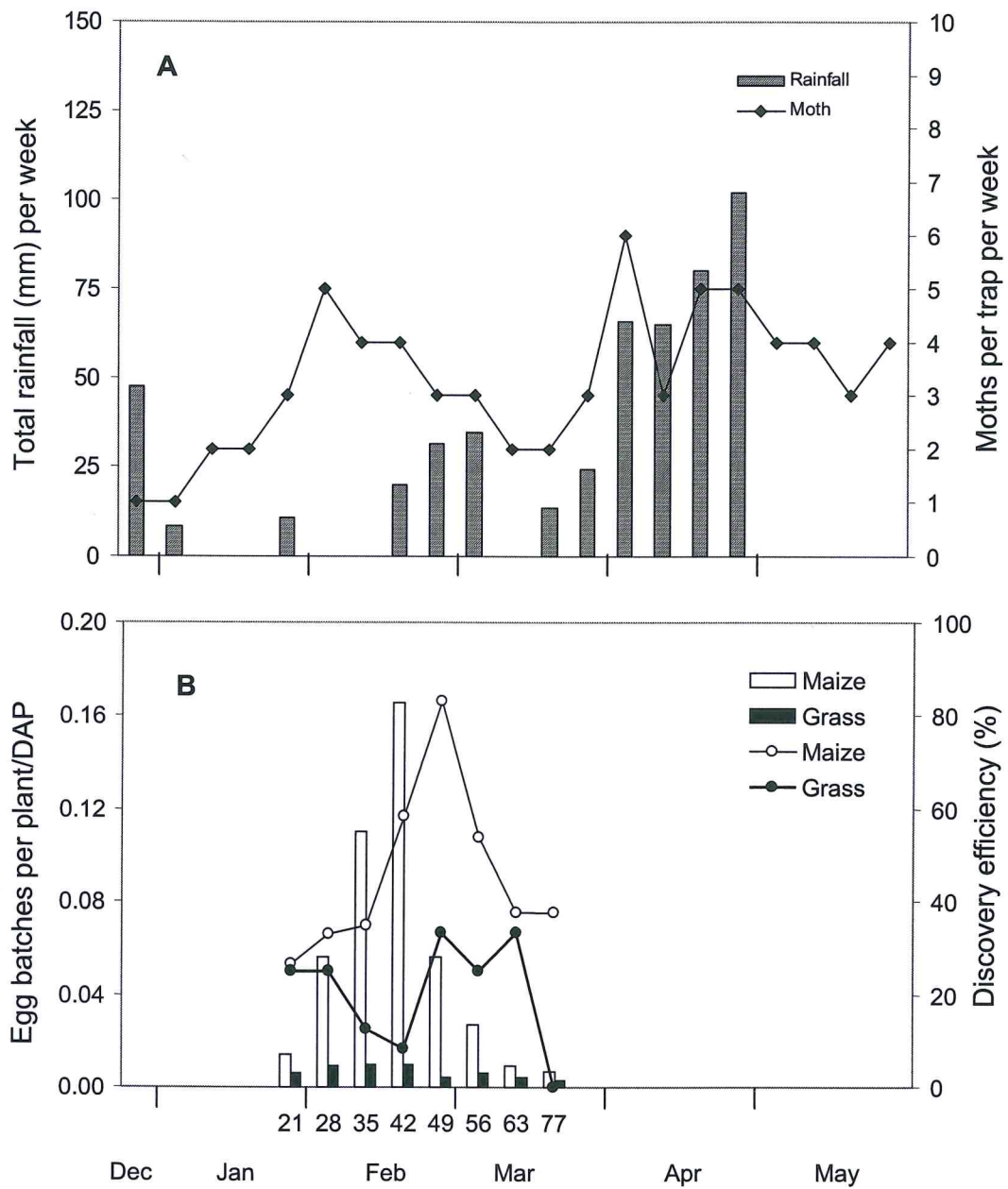


Fig. 2-4. Catches of *Busseola fusca* in relation to rainfall (A) and dynamics of stem borer and their natural enemies in the inland valleys fields (B). Number in the horizontal axis, represent days after planting of maize (DAP); discovery efficiency is the percentage of egg batches per field, with parasitoids.

Table 2.3. Correlation matrix of cumulative rainfall, adult catches per week and weekly egg batches and egg batch parasitism (%) recorded on maize and grasses during the dry season of 2004

	1	2	3	4	5	6
1 Rainfall (mm)	-					
2 Moth (adult)	0.81*	-				
3 Egg batch-maize	-0.49	0.64*	-			
4 Egg batch-grasses	-0.69	0.58*	0.80*	-		
5 Parasitism-maize	0.27	-0.05	0.29	-0.18	-	
6 Parasitism-grasses	0.10	-0.03	-0.35	-0.24	0.51*	-

**r* values with $P < 0.05$.

Table 2.4. Larva abundance (average \pm SE) of stem borers in the maize stubbles, inland valleys maize fields and wild grasses, during the dry season of 2004.

Source of infestation	Period	<i>Busseola fusca</i>	<i>Sesamia</i> spp.	<i>Eldana saccharina</i>
Maize stubble	January	0.537 \pm 0.03a	0.016 \pm 0.01a	0.372 \pm 0.04a
	February	0.131 \pm 0.03b	0.034 \pm 0.01a	0.374 \pm 0.04a
	March	0.070 \pm 0.03b	0.012 \pm 0.01a	0.100 \pm 0.04b
Inland valleys	at Harvest ¹	1.467 \pm 0.10a	0.033 \pm 0.01a	0.714 \pm 0.03a
Maize stubble	at Harvest	0.031 \pm 0.11b	0.023 \pm 0.01a	0.046 \pm 0.04b
Wild grasses	at Harvest	0.010 \pm 0.10b	0.005 \pm 0.01b	0.010 \pm 0.03b

Note: ¹, inland valley's maize fields were harvested between March and April; within column means followed by the same letter are not significantly different at $P < 0.05$ (t-test).

Sesamia spp. did not significantly differ between sampling months, while the highest larval densities of *E. saccharina* were found in January-February (Table 2.4). During the time of harvest of IV maize, the lowest borer larval densities were found on grasses. On maize, *B. fusca* and *E. saccharina* larval densities were 47.3 and 15.5 times, respectively, higher than those collected on old maize stubbles, while no difference was found for *Sesamia* spp. between IV maize and old maize stubbles (Table 2.4).

Seasonal variation in plant growth, damage variables and maize yields

Plant damage variables significantly varied with year and season (Table 2.5). The percentage of stem tunnelling and cob damage were 3 to 15 times higher in the long and short seasons than in the dry season (Table 2.5). The highest percentage of stem tunnelling in 2002 was found during the long rainy season, while in 2003 and 2004 no significant differences were found between the long and short rainy seasons. The same trend was observed for percentage of cob damage (Table 2.5). By contrast, the percentage of cob filling was generally higher during the dry season than in the long and short rainy seasons. Lowest cob filling was found in the long rainy season of 2002.

Plant growth and yield variables also varied significantly with year and season (Table 2.5). In 2002, the tallest plants were found during the dry and short rainy seasons, while in 2003 they were found in the long rainy season. There was no difference in plant height between seasons in 2004. Grain yield and marketable cob index were generally highest in the dry season, and they were 1.1 to 2 times higher than in the long and short rainy seasons.

Table 2.6 shows the characteristics of marketable cobs. The price of fresh cobs increased significantly with fresh cob weight (Price = 0.335*cob weight - 9.569; $r^2 = 0.95$, $P = 0.023$), while the cob weight was significantly positively correlated with the cob size ($r^2 > 0.88$, $P < 0.001$) and negatively related with the percentage of cob damage ($r^2 = -0.44$, $P < 0.001$).

Table 2.5. Average (\pm SE) plant damage variables (%), plant height, maize grains yield and marketable ear index during the dry, long and short rainy season (DS, LR and SR respectively) of 2002, 2003 and 2004

Season	Plant damage variables											
	% stem tunnelling			% ear damage			% ear filling					
	2002	2003	2004	2002	2003	2004	2002	2003	2004	2002	2003	2004
DS	2.0 \pm 3.1c	3.7 \pm 1.4b	1.3 \pm 1.7b	1.6 \pm 4.3b	1.5 \pm 1.1b	0.8 \pm 1.7b	88.2 \pm 4.9a	97.4 \pm 3.1a	96.8 \pm 2.7a			
LR	17.8 \pm 2.2a	9.9 \pm 1.0a	11.8 \pm 1.5a	12.4 \pm 3.0a	5.1 \pm 0.8a	8.1 \pm 1.4a	60.4 \pm 3.4b	89.5 \pm 2.3b	89.3 \pm 2.3b			
SR	9.5 \pm 1.7b	8.7 \pm 0.94a	15.7 \pm 1.9a	6.1 \pm 2.4b	5.0 \pm 0.7a	11.9 \pm 1.8a	95.6 \pm 2.7a	88.7 \pm 2.1b	81.5 \pm 3.0c			
	Plant growth and yield parameters											
	Plant height (cm)			Grain yield			MCI					
	2002	2003	2004	2002	2003	2004	2002	2003	2004			
DS	220.9 \pm 8.7a	211.4 \pm 5.9b	218.4 \pm 7.2	2.349 \pm 0.19a	2.035 \pm 0.13	2.047 \pm 0.14a	2.583 \pm 0.18a	2.144 \pm 0.14	2.250 \pm 0.15a			
LR	193.4 \pm 6.1b	228.8 \pm 4.4a	212.3 \pm 6.0	1.344 \pm 0.14b	1.709 \pm 0.10	1.603 \pm 0.12b	1.450 \pm 0.13b	1.809 \pm 0.11	1.823 \pm 0.13b			
SR	212.7 \pm 4.9a	206.5 \pm 3.9b	199.1 \pm 7.8	1.865 \pm 0.11c	1.841 \pm 0.09	1.030 \pm 0.16c	1.858 \pm 0.10c	1.944 \pm 0.09	1.210 \pm 0.16c			

Notes: Within column for a given variable, means followed by the same letter are not significantly different at $P < 0.05$ (t-test).

Table 2.6. Characterization of marketable cobs harvested in farmers' field

Variables	Marketable cob index ¹				LSD
	3	2	1	0	
Length (cm)	21.4	16.0	10.4	9.2	0.68
Width (cm)	5.1	3.9	3.0	2.1	0.20
Fresh ear weight (g)	263.5	161.2	85.0	51.7	16.37
% Ear damage	0.0	0.0	1.3	10.4	2.58
% Ear filling	100.0	99.8	91.9	46.6	7.81
Price in FCFA ²	75	50	25	0	-

¹, Scale used: 0 = ear not marketable, 1 = low market value, 2 = good market value, 3 = high market value; ², 540 F CFA = 1 US=\$.

Discussion

Busseola fusca was the predominant borer species in the entire inland valley-upland continuum as also reported by Cardwell *et al.* (1997), Ndemah *et al.* (2001a) and Ndemah and Schulthess (2002). Levels of borer infestations varied significantly with season and year. From observations made in different countries in sub-Saharan Africa (e.g., Bowden, 1954; Gounou *et al.*, 1994; Schulthess *et al.*, 1997; Cardwell, *et al.*, 1997; Ndemah, 1999) the two principal limiting factors affecting the build-up of maize stem borer populations are parasitoids and a prolonged dry season, the latter causing high mortality of immatures, as shown by a disappearance rate of 87% for *B. fusca* during the dry season of 2004, or an extended diapause leading to smaller adult size, and, thus, reduced female fecundity during the onset of the next rainy season. Especially egg parasitism is recognized to be an important source of mortality affecting pest populations since the pest is killed before it damages the crop (Temerak, 1981). In the present study, egg parasitism was 1.2-1.8 times higher in the second than in the first seasons. Similarly, Ndemah *et al.* (2003) showed that the drastic decrease in *B. fusca* infestation from the first to the second seasons in 1995 in the humid forest zone of Cameroon was due to a rapid increase in egg parasitism by *Telenomus* spp. from 20 to 67%. Similar results were found for *S. calamistis* for the derived savannah of Benin with egg parasitism of more than 90 % during the late cropping season (Schulthess *et al.*, 2001). Moreover, in the present study, parasitism was not different between dry season and long rainy season of 2002, and it was higher

during the dry season than the rainy seasons in both 2003 and 2004, supporting the hypothesis that IVs play an important role for the population dynamics of parasitoids in the inland-upland continuum. Thus, the presence of an IV close to upland maize fields may explain the high variability of parasitism found between fields by Ndemah *et al.* (2003). Chabi-Olaye *et al.* (2001a) hypothesized, based on comparisons of egg retention capacity under host deprivation situations, female fecundity and sex ratio, that *T. busseolae* was probably a savannah species, adapted to long periods of host scarcity, while *T. isis* evolved in humid forest habitats where the dry season lasts only 2-3 months and hosts are available throughout the year. In the present study, *T. isis* was predominant in IVs while *T. busseolae* was the more common species in upland maize, thereby supporting the above hypothesis. The proportion of eggs in the IV belonging to *Sesamia* sp. was much higher than in upland fields, where more than 95 % of eggs stemmed from *B. fusca*. Chabi-Olaye *et al.* (2001 a & b), using eggs of *B. fusca* and three *Sesamia* species as hosts, showed that all four hosts yielded similar parasitism by *T. busseolae* and *T. isis*, egg emergence and sex ratios, thus, the differences in the prevalence of a parasitoid species between IV and upland fields were not due to differences in host suitability. In addition, life table studies carried out under constant temperatures showed that the intrinsic rates of increase were higher for *T. busseolae* than for *T. isis* (Chabi-Olaye *et al.*, 1997, 2001a). Thus for unknown reasons, *T. isis* outcompeted *T. busseolae* in the IVs. As also shown by Ndemah *et al.* (2001). *Sesamia* spp. densities are very low on upland maize and grasses are scarce in the humid forest zone of Cameroon (Ndemah *et al.*, 2003). Most probably *T. busseolae* migrates to the IVs at onset of the dry season when *B. fusca* diapauses. This might explain the high discovery efficiency and parasitism in IVs during 2003 and 2004 and the overall lack of relationship between parasitism and egg batch density.

The percentage of eggs yielding both parasitoids was highest in the IVs during the dry season. As shown by Agboka *et al.* (2002), the two *Telenomus* species are able to discriminate between unparasitised hosts and hosts parasitised by the same or another species and tend not to super- or multiparasitise. They concluded that egg batches with two parasitoid species usually were not the result of multiparasitism but, rather, the exploitation of unparasitised eggs by a female of the other species.

Average egg batch density on wild grasses was much lower than on maize. However, depending on the species, grasses produce up to 20 times more tillers than maize (Ndemah *et al.*, 2000; F. Schulthess, unpubl. results), thus the overall egg density might still be considerable. However, the discovery efficiency was much lower indicating that host finding by the parasitoids is a function of egg batch density per unit area.

B. fusca moths were caught during the entire dry season and they were positively related with rainfall. It appears that part of the *B. fusca* population in the inland valleys did not enter diapause, and, thus, diapause is facultative in this species.

Busseola fusca densities on maize at harvest in IVs were 50 times higher than on maize stubbles in adjacent upland fields that were planted during the preceding season. Thus, the latter appear not to be an important source of infestation for newly planted upland maize fields, supporting again the hypothesis that IV maize planted during the dry season play an important role in the invasion of upland maize by pests and their natural enemies.

The most common larval parasitoid in the present study was *Actia* sp. while *C. sesamiae*, the most common parasitoid species of noctuids in eastern Africa (Kfir, 1992; Kfir and Bell, 1993), was scarce, and the tachinid *Sturmiopsis parasitica* Curran, the most common larval parasitoid in West Africa (F. Schulthess, unpubl. data). This corroborates results by Ndemah *et al.* (2001b) and Conlong (1990 & 1997) and opens up opportunities for the 'redistribution' biological control approach (Rao, 1965; Mohyuddin and Greathead, 1970; Mohyuddin, 1991; Schulthess *et al.* (1997).

The grain yields as well as the marketable cob index were 1.1 to 2 times higher in the dry season than in the long and short rainy seasons, indicating the importance of IVs for farmers in the humid forest zone of Cameroon.

Conclusion

A study as broad as an agroecosystem analysis necessarily has many perspectives. We have focused on the role of IVs, which are often planted with maize during the dry season, as reservoirs for both stem borers and their natural enemies, in the humid forest zones of Cameroon. Our findings show that *B. fusca*

can be active in the area throughout the year although populations of borers and their natural enemies in IV maize fields are rather low, suggesting that IVs maintain carry-over populations of not only *B. fusca* but also of its natural enemies as well as of alternative minor hosts such as *S. calamistis*, which do not diapause during the dry season. Thus, if crops grow concurrently in IVs and upland fields in an area, the chances of emerging females to encounter a suitable host plant for oviposition and survival of her progenies and ensuing overall pest densities in an area increase. Hence in IVs of Cameroon non-diapausing *B. fusca* mainly are responsible for the fast seasonal build-up of parasitoid populations on upland maize. IVs therefore should be targeted for augmentative releases of egg and larval parasitoids in biological control program against *B. fusca*.

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**Abundance, Dispersion and Parasitism of the Noctuid Stem Borer
Busseola fusca (Lepidoptera: Noctuidae) in Maize Intercropping
Patterns in the Humid Forest Zone of Southern Cameroon^a**

Abstract

This study was conducted in the humid forest zone of Cameroon, in 2002 and 2003. The main objective was to investigate the effects of intercropping on infestation level and parasitism of the noctuid maize stem borer *Busseola fusca* Fuller. Two trials were planted per year, one during the long and one during the short rainy season. Maize monocrops were compared with maize/legume or maize/cassava intercrops in two spatial arrangements: maize on alternate hills or in alternate rows. Spatial analyses showed that the stem borer egg batches were regularly dispersed in the maize monocrop and aggregated in the intercrops, as indicated by b , the index of dispersion of Taylor's power law. Depending on the crop association intercrops reduced the percentage of plants with stem borer eggs by 47.4-58.4 % and egg densities by 41.2-54.5 % compared to maize monocrop. Consequently larval densities were 44.4-61.5 % lower in intercrops compared to monocrops. Intercropping maize with non-host plants did not affect larval parasitism. However, up to twofold higher levels of egg parasitism by scelionid *Telenomus* spp. were recorded in inter- compared to monocrops, during the short rainy seasons of 2002 and 2003. No differences were found among the mixed cropping treatments and parasitism was lower during the long compared to short rainy seasons. It was proposed that differences in level of parasitism were due to density dependence effects rather than the effect of the presence of non-host plants in the system.

^a Published as Chabi-Olaye, A., Nolte, C., Schulthess, F. and Borgemeister, C. (2005) Abundance, dispersion and parasitism of the noctuid stem borer *Busseola fusca* (Lepidoptera: Noctuidae) in mono- and intercropped maize in the humid forest zone of southern Cameroon. *Bulletin of Entomological Research* 95, 169-177.

Introduction

In sub-Saharan Africa (SSA), maize is grown across all agro-ecological zones, in regions with uni- or bimodal rainfall patterns, allowing for one or two crops a year, respectively. In Cameroon, maize is among the two main important staples and grown from sea level to the highlands up to 2,000 m a.s.l. After the fall of the cocoa price, maize has become an important source of cash for farmers around large cities such as Yaoundé and Douala, which are situated in the humid forest zone (Ndemah and Schulthess, 2002). The major biotic constraints for maize production in the forest zone are among others, low soil fertility (Hauser and Nolte, 2002; Hauser *et al.*, 2002; Chapter 5) and lepidopterous stem borers such as the noctuid *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and the pyralid *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Cardwell *et al.*, 1997; Schulthess *et al.*, 1997; Ndemah *et al.*, 2001a; Ndemah *et al.*, 2003). Yield losses caused by maize stem borers range from 10-100 % depending on the season (Cardwell *et al.*, 1997; Ndemah and Schulthess, 2002).

Present work on Integrated Pest Management (IPM) of maize stemborers in the humid forest zone of Cameroon has focused on habitat management strategies, such as management of soil nutrients, mixed cropping and crop rotation systems. Chapter 5, showed that maize planted after a short fallow of leguminous food or cover crops (crop sequences) as a management practice is better than a continuous maize production system, with more or less similar effects on borer incidence as insecticide applications. Intercropping allows farmers a more efficient land use and ensures the availability of food through the seasons (Vandermeer, 1989; Mutsaers *et al.*, 1993). The importance of plant biodiversity in agro-ecosystems for reducing crop losses by pests has long been recognized (Litsinger and Moody, 1976; Okigbo and Greenland, 1976; Baliddawa, 1985). A considerable number of studies have shown that pest populations are higher, more frequent and cause greater yield losses in monocrops than in more diverse systems (Cromartie, 1981; Altieri and Letourneau, 1982; Kareiva, 1983; Risch *et al.*, 1983). Reasons for reduced pest numbers in more diversified systems can be attributed to, among others, (i) a decrease in food resource concentration (Tahvanainen and Root, 1972; Root, 1973), which increases the emigration of the ovipositing female from polycultures because of the difficulty in host finding and (ii) an increase in natural

enemy activities due to an increase in availability of suitable microhabitats, and diverse food resources such as nectar, pollen, and alternative hosts or prey (Root, 1973; Vandermeer, 1990). Some studies reported neutral or negative responses (reviewed by Russel, 1989; Andow, 1991; Altieri, 1994), reflecting the unpredictable nature of tritrophic interactions among plants, herbivores, and natural enemies. Thus, each system must be evaluated individually.

Intercropping maize with legumes or cassava is one of the most common systems in Cameroon. Ndemah (1999), in surveys in the humid forest zone, found a negative relationship between cassava density in mixed cropped fields and borer densities on maize indicating that intercropping with non host species might alleviate pest problems on maize. The present study tries to assess the effect of different cropping mixtures and arrangements on infestations of maize by stemborers and on associated parasitoids and to elucidate the mechanism responsible for changes in the dynamics of pest and natural enemies.

Materials and Methods

Experimental site

Experiments were set up at Nkometou (4° 05'N, 11° 33'E), a village 40 km west of Yaoundé, Cameroon, in 2002 and 2003. The trials were laid out in a 5-6-year old bush fallow dominated by *Chromolaena odorata* (L.) King and Rob. (Asteraceae). The site is characterized by a bimodal distribution of rainfall, with peaks in June and September and an annual precipitation of about 1,500 mm. The long and short rainy seasons last from mid March to mid July and from mid August to end of November, respectively. A short dry spell of about four weeks may occur between July and August. The major dry season starts in November and lasts through March. Rains started early in 2002 compared to 2003 and peaked in April (195 mm) and October (438 mm) vs. July (83 mm) and October (689 mm) in 2003. Generally, the predominance of stem borer species varies with season (Schulthess *et al.*, 1997). Thus, two trials were planted per year, one during the long and one during the short rainy season.

Experimental procedure and layout

Four crop species were used, i.e., a 110-day open pollinated maize variety, Cameroon Maize Series (CMS) 8704, a late maturing soybean *Glycine max* (L.) Merr. (var. TGX 1838-5E), an erect type cowpea *Vigna unguiculata* (L.) Walp. var. Asonten (both Fabaceae) and a local cassava variety named 'automatic' by farmers. Maize was monocropped or intercropped with cassava, cowpea or soybean. In the mixed cropping system, maize was planted 12-14 days after the non-host plant. Two spatial arrangements were used in mixed cropping, (i) within row arrangement where one maize plant was followed by a non-host plant, and (ii) strip planting in which two rows of maize followed by two rows of a non-maize crop, with one row of non-host plant as first and last row (borders) (herewith referred to as alternate hill (Ah) and alternate rows (Ar), respectively).

To enable measuring the effect of reduced borer densities on maize yield, the maize monocrop and all intercrops were grown with and without an insecticide treatment. The treatments were arranged in a completely randomised block design with four replications. Plots were 6 × 12 m each. The four blocks were established at 150-200 m distance from each other to reduce interactions between treatments. The distance between plots within a block was 1.5 m. Planting pattern and plant densities for maize, cowpea, soybean and cassava in monocrops and intercrops are shown in table 3.1. The planting patterns were chosen such that maize populations in all intercrops were the same except in the case of alternate hill planting with cassava. The plant populations of monocrops were chosen to be 'optimal' for the region, i.e. those that produce the highest yield. In the insecticide plots, maize plants were treated 35 and 49 days after planting (DAP) with carbofuran at ca. 1.5 a.i. kg ha⁻¹ by placing the granules in the whorl of the plant. The plots were kept weed-free to avoid interaction between weed growth and plant diversity.

Table 3.1. Planting patterns and plant populations (plants ha⁻¹) in the monocrops and intercrops

Treatments	Planting pattern		Seeds/hill		Plants ha ⁻¹	
	Maize	Associated crop	Maize	Associated crop	Maize	Associated crop
Maize-mono	0.75 × 0.50 m	-	2	-	53,333	-
Cassava-mono	-	1.00 × 1.00 m	-	1	-	10,000
Cowpea-mono	-	0.75 × 0.25 m	-	2	-	106,667
Soybean-mono	-	0.75 × 0.10 m	-	2	-	266,667
Maize-cassava/Ah	2.00 × 1.00 m	2.00 × 1.00 m	4	1	20,000	5,000
Maize-cassava/Ar	0.75 × 0.50 m	1.50 × 0.75 m	2	1	26,667	4,444
Maize-cowpea/Ah	0.75 × 0.50 m	0.75 × 0.50 m	1	2	26,667	53,333
Maize-cowpea/Ar	0.75 × 0.50 m	0.75 × 0.25 m	2	2	26,667	53,333
Maize-soybean/Ah	0.75 × 0.50 m	0.75 × 0.50 m	1	4	26,667	106,667
Maize-soybean/Ar	0.75 × 0.50 m	0.75 × 0.10 m	2	2	26,667	133,333

Assessment of stem borers and their natural enemies

During the vegetative stage, 80 and 40 maize plants/plot were checked weekly in monocrops and intercrops, respectively, for stem borer egg batches. Batches collected were brought to the laboratory for egg counts. Each batch was kept individually in a plastic container at $27 \pm 1^\circ\text{C}$ and $70 \pm 5\%$ of relative humidity for about one month, after which all larvae or parasitoids had emerged. Larvae hatching from partly parasitized egg batches were reared on pieces of maize cob to determine the borer species. Obviously parasitized but not hatched eggs were dissected for determination of parasitoid species. Parasitoids were identified to species-group level using the identification key of Polaszek *et al.* (1993). Three kinds of parasitization rates were calculated: a) mean egg parasitism per plot calculated as percentage of eggs parasitized within an individual egg batch, averaged over all egg batches found in a plot; b) the percentage of egg batches per plot with parasitoids. [This was referred to as 'discovery' efficiency by Bin and Vinson (1991) and provides information on the searching ability of a parasitoid]; and c) the percentage of eggs parasitized within a discovered egg batch, averaged over all egg batches per field termed 'parasitism efficiency' by Bin and Vinson (1991); parasitism efficiency is determined by parasitoid fecundity, host acceptance and the host patch exploitation strategy.

Larval densities were evaluated on 24 and 12 randomly sampled plants per plot in monocrops and intercrops, respectively. Depending on the season, sampling started 28 or 35 DAP and was continued at biweekly intervals until maturity of maize ears. At each sampling date, the number of plants showing borer damage was recorded, and each maize plant was dissected and the larvae and pupae of the same borer species per plant from the same plot were counted and placed together in wide-mouth jars. Larvae were maintained on a diet of young succulent stem and cob pieces of maize, and reared until borer pupation or parasitoid emergence. When changing the diet, dead larvae were placed individually in small round plastic containers and kept in the laboratory for parasitoid emergence. Borer pupae and parasitoid cocoons or pupae were kept individually in small round plastic containers for parasitoid or adult moth emergence. Parasitoids emerging from borer larvae and pupae were counted according to species and preserved in 70 % alcohol for later identification by the

taxonomists at the Insect Museum of the International Institute of Tropical Agriculture (IITA) in Cotonou, Benin.

Statistical analysis

Differences in average egg batches and larvae among the different cropping patterns were analysed by analysis of variance using the mixed model (SAS, 1997) for repeated measures over sampling dates. The treatments were considered as fixed effects while plants within replications were considered as random. An *F* test was used to test the significance of mean differences and least square mean (LSM) values were computed. The significance level was set at $P = 0.05$.

Taylor's (1961) power law was used to describe the dispersion of *B. fusca* egg batches, and of larvae and pupae combined. This law assumes a consistent relationship between the variance S^2 and mean m :

$$S^2 = am^b$$

where b is a measure of dispersion of the species, with $b > 1$ indicating 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 logarithm of the between plant variance ($\log S^2$) against the logarithm of mean density $\log(m)$, for each field at each sampling occasion. The General Linear Model (proc GLM) (SAS, 1997) was used to compare the b -values.

The parasitism of *B. fusca* was analysed by the maximum likelihood analysis using the proc logistic model (SAS, 1997) for categorical variables to identify the effects that differentiate the parasitism and non-parasitism of *B. fusca*. The proc logistic is invoked with the GLM-coding for class variables. Crop patterns and DAP were declared in class statements. In addition, contrast statements were used to test all the pair-wise comparisons between the seven levels of the crop patterns.

Results

Pest infestation and seasonal occurrence of stem borers on maize within the different cropping patterns

Eggs. In total 7,286 egg batches were collected in both year 2002 and 2003. More than 99.8 % of the eggs in the sub-samples stemmed from *B. fusca*, the remaining were *Sesamia* spp. No differences in batch size were found between treatments ($F = 5.72$, d.f. = 5053, $P = 0.251$) in both year, and the average across treatments was 16.9 eggs per batch (SE = 0.11). However, the average egg batches per plant varied significantly with season ($F = 136.3$, d.f. = 3, $P < 0.0001$) and days after planting (DAP) ($F = 38.7$, d.f. = 6, $P < 0.0001$). Therefore, data were presented separately for 2002, and 2003, respectively.

During the long rainy season in 2002, the first egg batches were collected 21 DAP. The numbers peaked at 42 DAP and then decreased until 63 DAP (significant quadratic trends, with $F = 589.6$, $P < 0.0001$; Fig. 3-1, 2002-LR). By contrast, during the short rainy season, the average egg batches per plant decreased significantly from 28 DAP to 56 DAP (significant linear trends with $F = 292.2$, $P < 0.0001$; Fig. 3-1, 2002-SR).

In 2003, few egg batches per plant (< 0.025) were collected during the long rainy seasons, and the numbers decreased with DAP (significant quadratic trends, with $F = 16.05$ $P < 0.001$; Fig. 3-1, 2003-LR). During the short rainy season, egg batch density increased from 21 DAP onwards to > 0.2 per plant (significant linear trends, with $F = 2129.9$, $P < 0.0001$; Fig. 3-1, 2003-SR).

The seasonal fluctuation of egg batches in intercrops followed that in the monocrops, but mostly at significantly lower densities. In 2002 during both seasons, the percent of plants with eggs and the number of egg batches per plant were around two times higher in mono- than intercropped maize (Table 3.2). In 2003, the proportion of plants with stem borer eggs and number of egg batches per plant did not vary significantly among treatments, during the long rainy season (Table 3.2), while during the short season, they were around 1.8 times higher in the monocropped compared to intercropped maize (Table 3.2). Egg batch densities tended to be lower on alternate hill than alternate row systems but

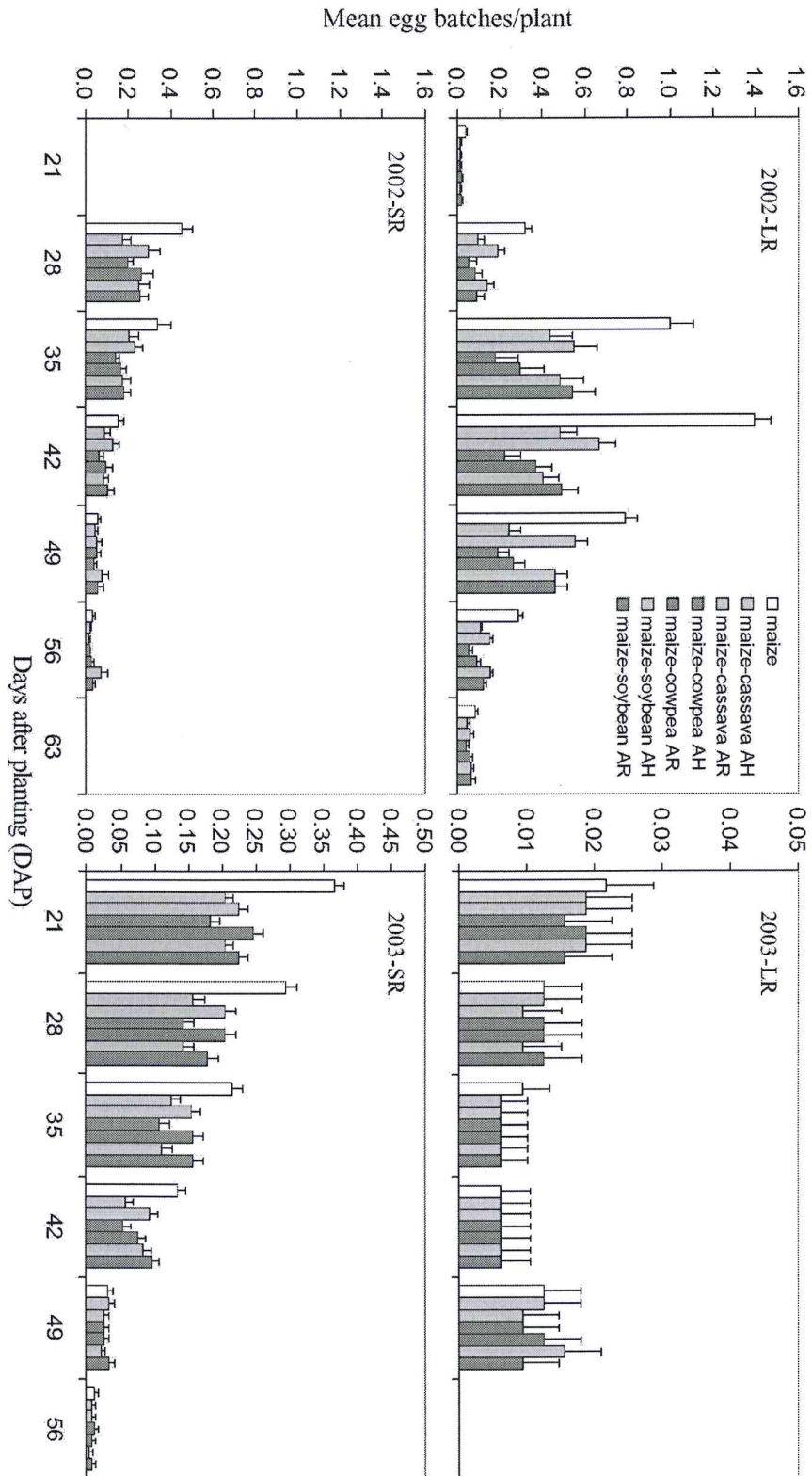


Fig. 3-1. Least square mean number of egg batches of *Busseola fusca* per plant, during the long (a) and short (b) rainy season of 2002 and the long (c) and short (d) rainy season of 2003. AH, alternate hill; AR, alternate row.

Table 3.2. Effects of maize intercropped with different non-host crops, arranged in alternative hill (Ah) and alternative row (Ar) on the least square mean of egg batches and larvae of *Busseola fusca* per plant, percentage plants with egg batches and percentage plant infestation per plot, during the long (LR) and short (SR) rainy season of 2002 and 2003.

Treatments	Growing season							
	Long rainy season			Short rainy season				
	% Plant with eggs	Egg batch per plant	% infested plant (PI)	<i>B. fusca</i> per plant	% Plant with eggs	Egg batch per plant	% infested plant (PI)	<i>B. fusca</i> per plant
2002								
Maize-mono	42.6 a	0.642 a	55.2 a	2.30 a	29.7 a	0.317 a	47.0 a	1.46 a
Maize-cassava/Ah	17.1 bc	0.232 c	26.7 b	1.38 b	14.5 b	0.156 bc	25.3 bc	0.59 b
Maize-cassava/Ar	23.3 b	0.357 b	36.0 b	1.48 b	18.9 b	0.218 b	30.8 b	0.81 b
Maize-cowpea/Ah	9.8 d	0.120 d	16.9 c	0.88 d	14.3 b	0.134 c	20.3 c	0.64 b
Maize-cowpea/Ar	15.9 cd	0.189 cd	28.9 b	0.99 d	15.8 b	0.176 bc	26.9 bc	0.74 b
Maize-soybean/Ah	18.8 bc	0.278 bc	30.7 b	1.21 c	15.1 b	0.172 bc	28.9 b	0.64 b
Maize-soybean/Ar	21.0 bc	0.290 bc	32.4 b	1.16 c	16.6 b	0.181 bc	29.4 b	0.73 b
SE	2.520	0.042	3.845	0.220	2.238	0.026	2.908	0.121
d.f.	329	329	329	105	161	161	273	105
2003								
Maize-mono	1.3	0.013	6.9	0.286	24.1 a	0.253 a	54.5 a	1.31 a
Maize-cassava/Ah	1.0	0.011	5.1	0.250	11.6 c	0.136 c	20.7 bc	0.54 c
Maize-cassava/Ar	1.0	0.010	4.7	0.260	14.6 b	0.169 b	28.0 b	0.99 b
Maize-cowpea/Ah	1.0	0.010	4.0	0.250	10.9 c	0.122 c	14.4 c	0.55 c
Maize-cowpea/Ar	1.1	0.011	4.6	0.276	15.0 b	0.171 b	21.7 bc	0.99 b
Maize-soybean/Ah	1.0	0.010	4.5	0.286	12.4 bc	0.135 c	19.3 bc	0.61 c
Maize-soybean/Ar	1.0	0.010	5.6	0.266	14.7 b	0.165 b	26.2 b	0.94 b
SE	0.263	0.003	0.981	0.068	1.081	0.014	3.917	0.140
d.f.	217	217	273	105	161	161	203	77

Notes: Within column for a given year, means followed by the same letter are not significantly different at $P < 0.05$ (t-test).

the differences were only consistently different during the short rains in 2003. Depending on season and compared to maize monocrop, intercropping maize with cassava, cowpea and soybean reduced percent plants with eggs by 41.3-37.6, 46.0-46.2 and 41.7-39.8 %, respectively.

Larvae. The average percentage of larval infestation and the number of *B. fusca* larvae per plant in the mono- and intercrops followed the same trend like the proportion of plants with stem borer eggs and the mean number of egg batches per plant. They were 1.8 and 2.0 times higher in the maize monocrop than in the intercrops in 2002, and 2.6-1.8 higher in the monocrop during the short rainy season of 2003 (Table 3.2). As for egg batches, larvae densities tended to be lower on alternate hill than alternate row systems.

Between-plant distribution of borers in maize monocrop and intercrops

For both *B. fusca* egg batches and larvae on maize within the different cropping patterns, the variance to mean relationship was well described by Taylor's power law (Table 3.3). The regressions between log (mean) and log (variance) were all highly significant, with high coefficients of determination (r^2) (Table 3.3). For egg batches, the indices of dispersion, i.e., b values, were significantly different from 1 in all cropping systems, showing a regular distribution ($b < 1$) in maize monocrops and an aggregated distribution ($b > 1$) in mixed cropping systems (Table 3.3). In the maize-soybean systems, the aggregation was significantly higher on the alternate hill than the alternate row treatment. When the dispersion analysis were done per season and across treatments, the regression between log (mean) and log (variance) showed an aggregation distribution of egg batches in the long rainy season of 2002 ($Y = 0.086 + 1.053 \cdot X$, $r^2 = 0.95$, $P < 0.0001$), when the average egg batch density was 0.20, and random distribution during the short rainy season of 2002 and 2003 ($Y = -0.019 + 0.990 \cdot X$, $r^2 = 0.96$, $P < 0.0001$) and ($Y = 0.041 + 1.020 \cdot X$, $r^2 = 0.96$, $P < 0.0001$) when average egg batch densities were 0.11 and 0.10, respectively. This analysis was not done for the long rainy season of 2003 due to the small amount of egg batches collected.

Table 3.3. Taylor's coefficients for numbers of *Busseola fusca* egg batches and larvae per maize plant. Maize was monocropped and intercropped with different non-host crops, arranged in alternative hill (Ah) and alternative row (Ar).

Host stage	n	Intercept (log a)	b ¹	r ²	F-value	P>F
Egg batches						
Maize-mono	109	-0.072	0.945 ± 0.018**c	0.96	2597.6	<0.001
Maize-cassava/Ah	96	0.108	1.078 ± 0.025**ab	0.95	1808.4	<0.001
Maize-cassava/Ar	100	0.139	1.118 ± 0.025**a	0.95	2063.0	<0.001
Maize-cowpea/Ah	99	0.096	1.075 ± 0.020**ab	0.97	2994.1	<0.001
Maize-cowpea/Ar	99	0.068	1.051 ± 0.019* b	0.97	2928.2	<0.001
Maize-soybean/Ah	99	0.135	1.100 ± 0.027**a	0.94	1635.1	<0.001
Maize-soybean/Ar	104	0.074	1.060 ± 0.020**b	0.96	2719.8	<0.001
Larvae						
Maize-mono	50	0.359	1.171 ± 0.064* c	0.88	339.1	<0.001
Maize-cassava/Ah	64	0.325	1.321 ± 0.051**b	0.91	664.7	<0.001
Maize-cassava/Ar	63	0.306	1.317 ± 0.059**b	0.89	503.9	<0.001
Maize-cowpea/Ah	56	0.411	1.469 ± 0.060**a	0.92	592.8	<0.001
Maize-cowpea/Ar	60	0.344	1.346 ± 0.064**b	0.88	439.3	<0.001
Maize-soybean/Ah	60	0.389	1.473 ± 0.060**a	0.91	607.9	<0.001
Maize-soybean/Ar	58	0.317	1.345 ± 0.059**b	0.90	513.0	<0.001

Notes: n, number of data points (sampling); ¹slope estimate ± s.e.; *slope significantly different from 1, F test, P < 0.01; **slope significantly different from 1, F test, P < 0.0001; separately for egg batches and larvae slopes followed with the same lowercase letters are not significantly different (P = 0.05, t-test).

The larvae showed an aggregated dispersion in all cropping systems (Table 3.3). Aggregation was significantly higher in mixed cropping systems than in monocropped maize. In maize-cowpea and maize-soybean mixtures aggregation was significantly higher in the alternate hill than the alternate row treatments (Table 3.3).

Parasitism

Identification of specimens from each egg batch showed that *Telenomus busseolae* (Gahan) and *T. isis* (Polaszek) (Hymenoptera: Scelionidae) were the only parasitoids attacking *B. fusca* eggs. Because identification of individual specimens is time-consuming, the numbers of both species were pooled for analyses. During the long rainy seasons in both years, discovery efficiency and egg parasitism did not vary significantly among treatments (Table 3.4). But they were 2.9 and 3.2 times, respectively, higher in 2003 compared to 2002. During the short rainy season, in both years, the discovery efficiency and egg parasitism were 1.8-2.0 times higher in inter- than in monocropped maize. Percent egg parasitism within egg batches (i.e., parasitoid efficiency) did not differ significantly between seasons and treatments ($F = 1.11$, d.f. = 1035, $P = 0.352$) in both years, and it was around 96.6 % (SE = 0.30).

Egg batch parasitism (discovery efficiency) decreased significantly with the egg batch density per plant ($Y = 32.99 - 45.73 * X$, $r^2 = 0.06$, $P < 0.0001$). If an egg batch was discovered the parasitoids tended to exploit all eggs in the batches with < 25 eggs per batch and then decreased with increase in egg density. The following function describes this relationship between the parasitism efficiency (Y) and egg density (X): $Y = -0.0595 * X^2 + 1.231 * X + 92.862$ ($F = 483.46$, $P < 0.0001$, $r^2 = 0.47$). Larval parasitism did not vary among treatments in both years and average parasitism was 4.7 and 6.6 % during the long and short rainy season, respectively, in 2002 (Table 3.4). No larval parasitoid was found during the long rainy season of 2003, while average parasitism was 8.1% during the short rainy season (Table 3.4). The most common species were *Actia* sp. (Diptera: Tachinidae), accounting for > 97 % of all larval parasitoids, and the two braconids *Dolichogenidea polaszeki* Walker and a *Cotesia* sp., but the latter was found in less than 10 larvae only.

Table 3.4. Effect of cropping system on the parasitism of egg batches, eggs and larvae of *Busseola fusca* during the long and short rainy season of 2002 and 2003 (Ah = alternative hill and Ar = alternative row).

Treatments	Growing season					
	Long rainy season			Short rainy season		
	Egg		% Larval parasitism	Egg		% Larval parasitism
	Discovery efficiency	% Egg parasitism		Discovery efficiency	% Egg parasitism	
2002						
Maize-mono	4.4	3.1	1.7	19.1 b	17.6 b	6.1
Maize-cassava/Ah	4.8	4.2	3.0	38.4 a	38.6 a	6.8
Maize-cassava/Ar	5.9	5.9	2.4	32.1 a	33.4 a	8.9
Maize-cowpea/Ah	3.5	4.1	4.4	33.6 a	29.1 a	5.3
Maize-cowpea/Ar	6.7	6.0	2.6	35.7 a	37.3 a	5.4
Maize-soybean/Ah	6.9	4.6	3.3	35.4 a	34.4 a	6.7
Maize-soybean/Ar	5.0	5.0	2.1	34.8 a	34.5 a	7.2
SE	1.89	1.82	1.46	4.48	3.49	3.38
d.f.	309	2000	127	156	1293	77
2003						
Maize-mono	13.9	16.4	-	17.4 c	18.9 c	7.6
Maize-cassava/Ah	18.3	15.4	-	43.5 a	42.1 a	4.3
Maize-cassava/Ar	12.5	13.8	-	30.7 b	31.7 b	4.7
Maize-cowpea/Ah	18.2	15.4	-	33.6 b	35.1 ab	18.1
Maize-cowpea/Ar	13.6	14.3	-	30.3 b	30.8 b	5.4
Maize-soybean/Ah	18.2	15.4	-	32.0 b	31.1 b	6.9
Maize-soybean/Ar	13.6	15.4	-	28.7 b	29.5 b	10.0
SE	9.88	10.24	-	2.12	3.51	4.51
d.f.	83	102	-	160	1336	64

Notes: Within column for a given experiment, means followed by the same letter are not significantly different at $P < 0.05$ (Wald χ^2 -test).

Overall, the logistic regression models showed that the cropping system had a significant impact on the levels of discovery efficiency and egg parasitism (Wald $\chi^2 = 57.75$, d.f. = 6, $P < 0.0001$ and Wald $\chi^2 = 1212.39$, d.f. = 6, $P < 0.0001$ respectively), while no association was found between the cropping patterns and larval parasitism (Wald $\chi^2 = 1.55$, d.f. = 6, $P = 0.956$). However, DAP significantly affected larval parasitism (Table 3.5). The likelihood of the discovery efficiency and egg parasitism were 48.6-53.6 % in the intercrops compared to the maize monocrop, while the highest odds ratios for discovery efficiency and egg parasitism were found between 21-28 DAP (Table 3.5). By contrast, for larval parasitism, the highest odds ratios (1.88 and 1.45) were found at 56-63 DAP (Table 3.5).

Discussion

Busseola fusca was the predominant borer species on maize in the humid forest of southern Cameroon, as also reported by Cardwell *et al.* (1997), Ndemah *et al.* (2001a) and Ndemah and Schulthess (2002). Levels of pest infestations varied significantly with season and year. In 2002, the highest infestation was found during the long rainy season, while in 2003 it was in the short rainy season. The first substantial rain in 2002 occurred earlier and the total rainfall prior to planting was higher than in 2003. Thus, in 2002 *B. fusca* larvae might have emerged from diapause (Usua, 1970) earlier and the build-up of pest populations was faster than in 2003. Swaine (1957) suggested that contact with water played an important role in the termination of *B. fusca* diapause and Ebenebe *et al.* (2000) showed a positive correlation between rainfall and flight activity of *B. fusca*. Thus, maize seedlings planted within two to three weeks after the onset of rain are likely to be severely attacked by first generation larvae (Swaine, 1957).

The numbers of egg batches were consistently lower on inter- compared to monocropped maize corroborating findings by Schulthess *et al.* (2004) from the stemborer *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) in a cassava-maize mixed cropping system in the humid tropics of West Africa. They suggested that the presence of the non-host cassava reduced the host finding ability of the ovipositing moth, supporting the *disruptive crop hypothesis* (Root, 1973; Vandermeer, 1989). This might have been due to changes in the physical

Table 3.5. Logistic regression analysis of the effect of cropping patterns and days after planting (DAP) on the egg batch (discovery efficiency) eggs and larval parasitism of *Busseola fusca* (data pooled across seasons)

Treatments	Discovery efficiency				Egg parasitism				Larval parasitism			
	Parameter estimate	SE	P-value	Odds ratio	Parameter estimate	SE	P-value	Odds ratio	Parameter estimate	SE	P-value	Odds ratio
Intercept	-1.19	0.07	<0.001		0.72	0.09	<0.001		-3.05	0.08	<0.001	
Maize-mono	-0.46	0.07	<0.001	0.63	-0.62	0.03	<0.001	0.54	-	-	-	-
Maize-cassava/Ah	0.45	0.08	0.001	1.57	0.31	0.04	<0.001	1.37	-	-	-	-
Maize-cassava/Ar	0.22	0.08	0.030	1.25	0.09	0.03	0.012	1.09	-	-	-	-
Maize-cowpea/Ah	0.16	0.10	0.036	1.18	0.11	0.04	0.004	1.12	-	-	-	-
Maize-cowpea/Ar	0.15	0.09	0.044	1.16	0.15	0.04	<0.001	1.16	-	-	-	-
Maize-soybean/Ah	-0.02	0.08	0.808	0.98	0.05	0.04	0.151	1.05	-	-	-	-
21 DAP	0.40	0.10	<0.001	1.49	-1.52	0.09	<0.001	0.22	-	-	-	-
28 DAP	0.08	0.09	0.330	1.09	-1.83	0.09	<0.001	0.16	-0.52	0.30	0.086	0.05
35 DAP	-0.38	0.09	<0.001	0.68	-2.22	0.09	<0.001	0.11	0.27	0.18	0.133	0.59
42 DAP	-0.96	0.10	<0.001	0.38	-2.73	0.09	<0.001	0.07	-0.25	0.17	0.152	1.31
49 DAP	-0.98	0.11	<0.001	0.38	-2.77	0.09	<0.001	0.06	0.63	0.18	<0.001	0.78
56 DAP	-0.45	0.14	0.001	0.64	-2.05	0.09	<0.001	0.13	0.37	0.14	0.009	1.88
63 DAP	-0.07	0.20	0.720	0.93	-2.28	0.11	<0.001	0.10	0.59	0.21	0.005	1.45

characteristics of the plant canopy or adverse chemical stimuli produced by the companion plants (Altieri *et al.*, 1978). For example, Khan *et al.* (1997) found that volatiles produced by molasses grass *Melinis minutiflora* Beauv. (Poaceae) repelled stem borers and considerably reduced oviposition of *C. partellus* in intercropped maize. In addition, Tahvanainen and Root (1972) stipulated, that intercropping lowers pest densities by reducing immigration into the crop or increasing emigration from the field. *Busseola fusca* oviposits between the leaf sheath and the stem (Kaufmann, 1983). First larval instars migrate to the whorl. It then either bores into the stem from the top after feeding on the whorl leaves causing the typical 'windows', or disperses to other plants. The presence of a non-host in the system very likely reduces the chances of the dispersing larvae to land on a suitable host thereby increasing larval mortality. This might be another reason for reduced larval densities in mixed compared to monocropping systems.

The indices for egg distribution, i.e., b values, showed a regular distribution of *B. fusca* egg batches in the maize monocrop and an aggregated distribution in the mixed cropping systems. There was higher aggregation in the alternate hill than alternate row systems. Ndemah *et al.* (2001b) reported a random distribution of *B. fusca* eggs on maize and an aggregated distribution on the elephant grass *Pennisetum purpureum* Moench. Sétamou and Schulthess (1995) found a regular distribution for *S. calamistis* egg batches on maize, while Schulthess *et al.* (2001), working with the same species, found that with increasing density the distribution changed from regular to random. This is in accordance with findings in the present study, when data were analyzed according to season rather than cropping system. Female noctuid stemborers very rarely oviposit more than one egg batch per plant. They avoid plants with egg batches and oviposit at a distance from an occupied plant leading to a regular distribution of egg batches (Sétamou and Schulthess, 1995). The authors argued that in view of the low carrying capacity of the thin stems of natural host plants (i.e. grasses) and the aggregated distribution of noctuid stemborer larvae, a regular distribution of egg batches would improve the chances of survival of young larvae. More than one egg batch per tiller or plant would lead to early destruction of the food source, causing cannibalism, forced emigration and exposure to predators, which results in increased larval mortality. Ndemah *et al.* (2001b) showed that the percentage of cases with more than one *B. fusca* egg batch per plant increased significantly with egg batch density in a

field and suggested that multiple egg batches are the result of overcrowding. Consequently, dispersion would change from regular to random and aggregated as egg batch density increases. However, in the present study, the analysis of data according to cropping system, showed a regular distribution with high densities in monocropped maize. By contrast, the same analysis showed aggregated distribution with low densities in mixed cropping, especially in alternate hill systems. It is suggested that the female moth marks the oviposition site to prevent oviposition of a second egg batch on the same plant or a plant nearby in order to increase the chances of survival of its offspring. Hence, the presence of a non-host plant and especially when planted as 'alternate hill', where a maize plant is always surrounded by four non-host plants, such markings might not be perceived. Thus, the same or a second female might oviposit on the same or a nearby plant, leading to aggregated distribution of egg batches. As a result, larval distribution tends to be more aggregated in such systems compared to monocropped maize or maize planted in alternate rows.

In this study levels of larval parasitism were generally low, corroborating results by Ndemah *et al.* (2001c) from maize and elephant grass, who also found *Actia* sp. to be the most common larval parasitoid. No differences were found between the monocrop and intercrops indicating that mixed cropping did not promote the activities of larval parasitoids confirming results by Schulthess *et al.* (2004) from a maize-cassava relay crop in Benin. By contrast, egg parasitism caused by *Telenomus* spp. was high during the short rainy season, and higher in inter- than in monocrops. Similar results were reported by Schulthess *et al.* (2004). In the present study, both discovery and parasitism efficiency decreased with increasing egg batch density. This suggests that the differences in parasitism between cropping systems were mainly due to density dependence effects, as also suggested by Schulthess *et al.* (2004), and that the non-host species had no or little direct effects on the performance of the parasitoids.

Conclusion

The present study is part of a project that seeks to develop a systems-based plant protection strategy, which can respond to pest-related production constraints in maize farming systems in the humid forest margins of Central Africa. In the

present work, emphasis was given to the effect of plant species diversity on *B. fusca*, the predominant maize stem borer in the region. Our findings indicate that intercropping maize with non-host plants reduce pest infestation and egg densities in intercrops compared to the maize monocrop and altered the distribution of egg batches in the system. Consequently, populations of *B. fusca* larvae on intercrops were lower, underlining the role of plant species diversity to regulate maize stem borer. Presently, we are investigating the net effects of reduced pest density and increased plant competition on grain yield losses and the productivity per unit area of land.

Relationships of Maize Intercropped and Stem Borer Damage to Maize Yield and Land-use Efficiency in the Humid Forest of Cameroon^b

Abstract

Stem borers are the most important maize pests in the humid forest zone of Cameroon. Field trials were run in the long and short rainy seasons of 2002 and 2003 to assess the level of damage and yield reductions caused by stem borers in monocropped maize and in maize intercropped with non-host plants such as cassava, cowpea and soybean. The intercrops were planted in two spatial arrangements, i.e., alternating hills or alternating rows. All intercrops and the maize monocrop were grown with and without insecticide treatment for assessment of maize yield loss due to borer attacks. The land-use efficiency of each mixed cropping system was evaluated by comparing it with the monocrop. The temporal fluctuation of larval infestations followed the same pattern in all cropping systems, but at the early stage of plant growth, larval densities were 21.3-48.1 % higher in the monocrops than in intercrops, and they tended to be higher in alternating rows than alternating hills arrangements. At harvest, however, pest densities did not significantly vary between treatments. Maize monocrops had 3.0-8.8 times more stems tunneled and 1.3-3.1 times more cob damage than intercrops. Each percentage increase in stem tunneling decreased maize grain yield by 1.10 and 1.84 g per plant, respectively, during the long and short rainy season in 2002, and by 5.39 and 1.41 g, respectively, in 2003. Maize yield losses due to stem borer were 1.8-3.0 times higher in monocrops than in intercrops. Intercrops had generally a higher land-use efficiency than monocrops, as indicated by land-equivalent-ratios and area-time-equivalent-ratios of > 1.0 . Land-use efficiency was similar in both spatial arrangements. At current price levels, the net production of mixed cropping systems was economically superior to controlling

^b Submitted as Chabi-Olaye, A., Nolte, C., Schulthess, F. and Borgemeister, C. (2005) Relationships of maize intercropped and stem borer damage to maize yield and land-use efficiency in the humid forest of Cameroon. *Bulletin of Entomological Research* (submitted).

stem borers with insecticide in monocropped maize. The maize-cassava intercrop yielded the highest land equivalent ratios and the highest replacement value of the intercrop. At medium intensity crop yields this system is thus recommendable for land-constrained poor farmers who do not use external inputs such as fertilizer and insecticides.

Introduction

In most of sub-Saharan Africa (SSA), maize is the predominant cereal in terms of both acreage and tonnage. In Cameroon, maize is among the two main staples and grown from sea level to the highlands of up to 2,000 m a.s.l. In the humid forest zone, maize production has been stimulated by rising demands of urban consumers and in the vicinity of urban centres it is increasingly grown as a cash crop (Ndemah, 1999).

In SSA, maize is attacked by a complex of stem and cob borer species belonging to the families of Noctuidae, Pyralidae and Crambidae (see overview by Polaszek, 1998). Common borer species in the humid forest zones of Cameroon are the noctuid *Busseola fusca* (Fuller), which is the most widely distributed and abundant species, and the pyralid *Eldana saccharina* (Walker), which can become important during the second season (Cardwell *et al.*, 1997; Schulthess *et al.*, 1997; Ndemah, *et al.*, 2001).

Yield reductions due to borers occur as a result of leaf feeding, stem tunnelling, direct damage to grain (Bosque-Pérez and Mareck, 1991; Cardwell *et al.*, 1997; Sétamou *et al.*, 2000a), and are aggravated by the poor nutritional status of the plant (Sétamou *et al.*, 1995). Maize yield can be reduced by 10-100 % depending on the season (Cardwell *et al.*, 1997; Ndemah and Schulthess, 2002).

Many studies in tropical as well as temperate zones reported decreased pest densities in diversified systems (Altieri and Letourneau, 1982; Risch *et al.*, 1983; Andow, 1991; Thies and Tscharrntke, 1999; Kruess and Tscharrntke, 2000). In Africa, such techniques include pest diversion or trap cropping (Khan *et al.*, 1997; Ndemah *et al.*, 2002) and mixed cropping (Litsinger and Moody, 1976; Okigbo and Greenland, 1976; Baliddawa, 1985; Schulthess *et al.*, 2004). There are a number of studies in Africa that have shown a reduction in stem borer densities when maize was intercropped with non-hosts such as cassava or legumes. However,

most of them were carried out in eastern Africa and dealt with the invasive crambid stem borer *Chilo partellus* (Swinhoe) (see overview by van den Berg *et al.*, 1998). Recent work in western Africa showed, that maize intercropped with cassava or grain legumes considerably reduced the amount of eggs of the noctuids *Sesamia calamistis* Hampson (Schulthess *et al.*, 2004) and *B. fusca* (chapter 3), as a result of reduced host finding by the ovipositing adult moths. These results support the *disruptive crop hypothesis* of Root (1973) and Vandermeer (1989).

The present study attempts to assess the effects of different crop mixtures and planting arrangements on pest infestations and yield losses in maize in the humid forest zone of Cameroon, during four consecutive cropping seasons.

Materials and Methods

Experimental site and procedure as well as layout are described in the previous chapter (chapter 3).

Plant growth and damage assessment

During the vegetative and reproductive stages, 24 and 12 maize plants were taken from each insecticide-free plot in monocrops and intercrops, respectively. Plant height, number of borers, and plant damage variables (i.e., number of nodes and internodes bored, tunnel length in cm) were recorded.

At harvest, the same data as described above were collected and in addition cob damage by borers, estimated as the percentage of grains consumed, was determined.

Crop yield assessment within cropping patterns

At harvest, yield parameters were gathered on all plots. Cowpea was harvested at 90 DAP, soybean and maize at 110, and cassava at 365 DAP. Each plot was divided into four quadrants, and a predetermined sub-plot of 3 m² was harvested from each. Plant stands were assessed per plot for all crop species. For determining dry matter yields, sub-samples of grains were dried in an oven for about 7 days at 65°C.

In the maize plots, plants were counted; cobs were removed, dehusked and weighed. A sub-sample of 5 cobs per quadrant was weighed, dried and the dry grains removed and weighed to determine grain dry matter yield.

For legumes, the total weight of pods per plot was recorded, and seeds were removed and weighed. A sub-sample of 100 g of seeds was weighed, and dried to assess the grain dry matter yield per plot.

Cassava yield was analyzed as both fresh and dry root weight, determined approximately 12 months after planting. Plants were uprooted and the storage roots were weighed. From each plot, a sub-sample of about 2 kg was taken from different roots and dried in the oven at 105°C for estimation of root dry matter (DM). The total root DM was estimated by multiplying the fresh root weight with the proportion of DM.

Statistical analysis

The egg-to-larva mortalities was estimated at 42 and 63 DAP. To this end, the total number of larvae collected at 42 or 63 DAP were divided by the cumulative amounts of eggs collected up to 35 or 56 DAP, respectively, a method described in detail in chapter 3. The analyses were done separately for each cropping season. Differences in plant height, total dry matter, grain weight, mortalities and damage variables were analyzed by analysis of variance (ANOVA), using the general linear model (GLM) procedure of SAS (SAS, 1997). Least squares means (LSM) were separated using the t-test. The significance level was set at $P = 0.05$.

Correlation coefficients were calculated using data pooled across seasons and treatments. A stepwise multiple regression was performed to investigate the time during the cropping cycle at which borer infestations significantly contributed to yield losses. Variables were retained in the model at $P = 0.15$.

Maize grain yield loss. Yield data obtained from paired treatments (plots having the same cropping pattern with and without insecticide treatment) were compared using the t-test statistics for test of significance. Maize grain yield losses due to stem borer were assessed on an area basis as follows:

$$100 \times (Y_i - Y_t) / Y_i$$

where Y_i and Y_t are the mean yields of protected and non-protected plots, respectively.

Estimation of the land-use efficiency. Both area and time factors have to be considered to quantify land-use efficiency if the yield of short duration crops, such as maize and cowpea, is to be compared with long-duration crops, such as cassava (Mason *et al.*, 1986; Hiebsch and McCollum, 1987; Mutsaers *et al.*, 1993). Thus, the overall efficiency of each cropping pattern was assessed using both the land-equivalent-ratio (LER) and the area-time-equivalent-ratio (ATER).

As defined by Mead and Willey (1980), the LER is the area that would be needed in sole crops to obtain the same total yield as produced by unit area in the crops mixture. It is calculated as:

$$LER = (I_a/M_a) + (I_b/M_b)$$

where I_a and I_b are the yields of crops a and b, respectively, in intercropping; M_a and M_b are the yields of crops a and b, respectively, in the monocrop. If the LER is > 1 , the intercrop is more efficient in terms of land use and if it is < 1 the monoculture is more efficient.

ATER was calculated according to Hiebsch (1978), modified by Mutsaers *et al.* (1993), as follows:

$$ATER = [(t_a/t_i) \times (I_a/M_a)] + [(t_b/t_i) \times (I_b/M_b)]$$

where t_a and t_b are the growth period in days of crops a and b, respectively, in monocropping and t_i the total growing period in days of the intercrop system. The dry season in days was deducted from t_{cassava} according to Mutsaers *et al.*, (1993), so as to account for the fact that growth of most crops is arrested during that time.

A second objective of this experiment was to evaluate the effect of intercropping on stem borer infestation vis-à-vis insecticide use in monocropped maize. To assess the two systems, we have to compare the net production of the intercrop with the net production of the monocrop. This requires calculating a 'replacement value of the intercrop' (RVI) according to Vandermeer (1989) as follows:

$$RVI = (p_m \times I_m + p_a \times I_a) / (p_m \times M_m - p_i)$$

Where I_m and I_a are the yields of maize and the associated crop (a), respectively, in intercropping and M_m is the yield of maize, in the monocrop, treated with insecticide. The prices of maize (p_m), the associated crop (p_a) and the cost of the insecticide (p_i) are also taken into account. RVI values > 1.0 indicates that the

intercrop is advantageous compared to the monocrop with insecticide use. The following prices were taken for calculating the RVI: maize = 100 FCFA kg⁻¹, cassava = 50 FCFA kg⁻¹ fresh roots; cowpea = 400 FCFA kg⁻¹, soybean = 300 FCFA kg⁻¹ and furadan = 2,500 FCFA kg⁻¹, with 540 FCFA = 1 US-\$.

Results

Abundance of borers in the different cropping patterns

During the long rainy season of 2002, colonization of plants by stem borer larvae started early (i.e., 28 DAP) on monocropped maize with 0.15 larvae/plant, when no larvae were yet found in the intercrops. Thereafter larval densities increased in both monocrop and intercrop and peaked at 56 DAP to decrease again until 70 DAP (Table 4.1). By contrast, larval densities decreased significantly with DAP during the short rainy season of 2002 ($F = 18.31$, d.f. = 3, $P < 0.0001$), and the long rainy season of 2003 ($F = 10.17$, d.f. = 3, $P < 0.0001$). During the short rainy season of 2003, pest densities increased from 28 DAP on both monocrop and intercrops and peaked at 42 DAP, to decrease again until 70 DAP. Overall, the temporal fluctuation of larval infestations in intercrops more or less followed that in the monocrop, but densities were considerably and significantly lower in mixed cropping treatments, during both seasons of 2002 and during the short rainy season of 2003. However, pest numbers did not significantly differ among treatments during the long rainy season of 2003 (Table 4.1). The number of larvae in both experiments were higher in the monocrop than in intercrops by 41.7-100 % at DAP < 56 and by 21.3-48.1 % at 70-77 DAP.

The egg-to-larva mortalities were not significantly affected by the cropping pattern ($F = 0.03$, d.f. = 6, $P = 0.999$) and ranged between 95.5-96.4 % and 98.5-98.8 at 42 and 63 DAP, respectively.

Five borer species were found at harvest. *B. fusca* was predominant in all seasons, accounting for 76.4 % of all species, followed by *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) with 15.5 %, *E. saccharina* with 5.2 %, *Cryptophlebia leucotreta* Meyrick (Lepidoptera: Tortricidae) with 1.8 % and *Sesamia* spp. (Lepidoptera: Noctuidae) with 1.1 % (Table 4.2). Densities of the other species did not significantly vary among treatments both in the insecticide-treated and untreated plots (Table 4.2). But, *B. fusca* larval densities were

Table 4.1. Effects of maize intercropped with different non-host crops in alternative hills (Ah) and alternative rows (Ar) on the least square means of number of *Busseola fusca* per plant at different days after planting (DAP) during the long and short rainy seasons of 2002 and 2003

Treatments	Growing season							
	Long rainy season				Short rainy season			
2002	28 DAP	42 DAP	56 DAP	70 DAP	35 DAP	49 DAP	63 DAP	77 DAP
Maize-mono	0.146	2.754 a	3.365 a	2.948 a	2.146 a	1.854 a	1.412 a	0.417
Maize-cassava/Ah	0.000	1.639 b	2.156 b	1.719 b	0.937 b	0.625 b	0.437 b	0.344
Maize-cassava/Ar	0.000	1.698 b	2.458 b	1.750 b	1.396 b	0.875 b	0.604 b	0.354
Maize-cowpea/Ah	0.000	0.892 d	1.250 c	1.167 c	1.125 b	0.750 b	0.437 b	0.229
Maize-cowpea/Ar	0.000	1.125 cd	1.437 c	1.354 c	1.229 b	0.854 b	0.521 b	0.375
Maize-soybean/Ah	0.000	1.290 c	1.948 b	1.604 b	1.042 b	0.667 b	0.479 b	0.354
Maize-soybean/Ar	0.000	1.250 c	1.812 b	1.583 b	1.312 b	0.854 b	0.458 b	0.312
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.003	<0.001	<0.001	0.930
SE	0.010	0.127	0.213	0.092	0.180	0.162	0.137	0.107
d.f.	21	21	21	21	21	21	21	21
2003	35 DAP	49 DAP	63 DAP	77 DAP	28 DAP	42 DAP	56 DAP	70 DAP
Maize-mono	0.698	0.302	0.094	0.052	1.764 a	1.986 a	1.250 a	0.250
Maize-cassava/Ah	0.604	0.271	0.083	0.042	0.694 c	0.778 c	0.500 c	0.167
Maize-cassava/Ar	0.646	0.250	0.104	0.042	1.333 b	1.583 b	0.806 b	0.222
Maize-cowpea/Ah	0.625	0.250	0.083	0.042	0.750 c	0.833 c	0.472 c	0.139
Maize-cowpea/Ar	0.667	0.292	0.083	0.062	1.250 b	1.611 b	0.917 b	0.167
Maize-soybean/Ah	0.708	0.271	0.125	0.042	0.833 c	0.889 c	0.583 c	0.139
Maize-soybean/Ar	0.687	0.208	0.104	0.062	1.306 b	1.472 b	0.778 b	0.222
P-value	0.941	0.938	0.997	0.999	<0.0001	<0.0001	<0.0001	0.777
SE	0.074	0.058	0.053	0.042	0.067	0.054	0.051	0.061
d.f.	21	21	21	21	14	14	14	14

Notes: Within column for a given experiment, means followed by the same letter are not significantly different at $P < 0.05$ (t-test).

Table 4.2. Least square means of number of borer larvae per plant collected in the different cropping patterns at harvest during the long and short rainy season of 2002 and 2003.

Treatments	Growing season								
	Long rainy season				Short rainy season				
	Busseola fusca		Others		Busseola fusca		Others		
	IP	TP	IP	TP	IP	TP	IP	TP	
2002									
Maize-mono	1.36 A	0.24 B	0.97	0.93	0.17 A	0.03 B	0.19	0.23	
Maize-cassava/Ah	1.31 A	0.22 B	0.63	0.53	0.27 A	0.03 B	0.23	0.10	
Maize-cassava/Ar	1.28 A	0.27 B	0.96	0.98	0.25 A	0.04 B	0.21	0.23	
Maize-cowpea/Ah	1.25 A	0.10 B	0.65	0.52	0.23 A	0.04 B	0.10	0.33	
Maize-cowpea/Ar	1.20 A	0.29 B	0.88	0.71	0.21 A	0.01 B	0.25	0.12	
Maize-soybean/Ah	1.32 A	0.25 B	0.92	0.65	0.19 A	0.04 B	0.17	0.19	
Maize-soybean/Ar	1.22 A	0.38 B	1.10	1.30	0.23 A	0.01 B	0.17	0.14	
P-value	<0.001		0.868		<0.001		0.928		
SE	0.18		0.30		0.04		0.09		
d.f.	42		42		42		42		
2003									
Maize-mono	0.15 A	0.04 B	0.38	0.29	0.10	0.07	0.49	0.46	
Maize-cassava/Ah	0.18 A	0.04 B	0.10	0.10	0.06	0.08	0.48	0.85	
Maize-cassava/Ar	0.17 A	0.02 B	0.17	0.13	0.11	0.06	0.39	0.78	
Maize-cowpea/Ah	0.15 A	0.02 B	0.13	0.10	0.08	0.05	0.46	0.43	
Maize-cowpea/Ar	0.19 A	0.02 B	0.25	0.15	0.06	0.08	0.67	0.62	
Maize-soybean/Ah	0.14 A	0.04 B	0.38	0.10	0.09	0.08	0.93	0.47	
Maize-soybean/Ar	0.17 A	0.04 B	0.24	0.42	0.08	0.05	0.56	0.40	
P-value	0.040		0.374		0.999		0.885		
SE	0.05		0.16		0.05		0.31		
d.f.	42		42		28		28		

Notes: IP, infested plot; TP, insecticide-treated plot. Others consisting of *M. nigricornis* (15.5%), *E. saccharina* (5.2%), *C. leucotreta* (1.8%) and *S. calamistis* (1.1%) of total borers collected. Within rows, means followed by the same capital letter are not significantly different (comparison between treated and non-treated plots for each cropping pattern) at $P < 0.05$ (t-test).

significantly lower in insecticide treated than in untreated plots during the long and short rainy season of 2002 and during the long rainy season of 2003 (Table 4.2). During the short rainy season of 2003 however, *B. fusca* densities did not significantly vary among treatments both in the insecticide-treated and untreated plots.

Maize yields and yields losses

During the long and short rainy season of experiment 02 and during the short rainy season of experiment 03, maize grains yields in insecticide-treated plots were 38.6- 54.7 % higher in monocrops than in intercrops (Table 4.3). Yield differences between monocrops and intercrops were lower in the infested plots, with maize yields being 11.9-40.2 % higher in monocrop than in intercrops, during the long and short rainy season of 2002 and during the short rainy season of 2003 (Table 4.3). The maize grain yields did not significantly vary among mixed cropping treatments during the long rainy season of 2003 (Table 4.3). Maize yields were 44.6-50.9 % higher in the monocrop than in intercrops. In both insecticide-treated and untreated plots there were no differences in yields between alternate hill and alternate row treatments.

Maize grains yields were significantly higher ($P < 0.0001$) in insecticide-treated than in untreated plots during the long and short rainy seasons of 2002 and during the short rainy season of 2003 (Table 4.3). Hence, yield losses due to borer attack were 1.8-3.0 times higher in monocropped than in intercropped maize, during the long and short rainy seasons of 2002, and during the short rainy season of 2003. By contrast, yield losses were much lower and not significantly different between mono- and intercrop during the long rainy season of 2003 (Table 4.3).

Relationships between maize yield, plant growth and damage variables

Plant height at harvest was significantly positively related to yield variables such as cob filling, fresh cob weight and dry grain weight ($r > 0.54$, $P < 0.0001$) while no relationship was found with larval densities and damage variables. Of all borers encountered at harvest, only *B. fusca* was significantly positively correlated with % stem tunnelling ($r = 0.35$, $P < 0.0001$), which, in turn, was significantly negatively related to grain weight per plant ($r = -0.41$, $P < 0.0001$). By contrast, no

association was found between grain weight and larval density. However, the relationship between *B. fusca* and percent stem tunnelling was highly significant during the earlier stages of plant growth but the significance decreased with age of the plant (Fig. 4-1). The regression of percent stem tunneled versus grain weight showed that a one percent increase in stem tunnelling decreased maize grain yield by 1.10 and 1.84 g per plant, respectively, during the long and short rainy season of 2002 and by 5.39 and 1.41 g, respectively, in 2003 (Fig. 4-2).

The grain yield per plant was negatively related to the number of larvae found at early, but not at late plant growth: 28-35 DAP ($r^2 = 0.25$, $P < 0.0001$), 42-49 DAP ($r^2 = 0.33$, $P < 0.0001$), 56-63 DAP ($r^2 = 0.07$, $P = 0.0043$) and 70-77 DAP ($r^2 = 0.005$, $P = 0.4623$). Stepwise multiple regression showed that borer infestations at 28-35 DAP and 42-49 DAP were significantly negatively related to yield (Table 4.4).

The percentage of stem tunneled, internodes bored and cobs damaged did not significantly vary among treatments in the insecticide-treated plots (Table 4.5). In insecticide-free plots, % stem tunneled was 3.0-8.8 times higher in monocrops than in intercrops during the long and short rainy seasons of 2002 and during the short rainy season of 2003 (Table 4.5). No differences were found during the long rainy season of 2003. In the insecticide-free plots, % internodes bored was not affected by cropping patterns in both experiments of 2002 and 2003 (Table 4.5), while % ear damaged was 1.3-3.1 times higher in mono- than in intercrops, during the long rainy season of 2002 and during the short rainy season of 2003 (Table 4.5). No differences were found during the other seasons (Table 4.5).

Yield of associated crops and land-use efficiency

Cassava. The dry matter yield of cassava roots did not significantly vary among treatments planted during the long rainy seasons, and was on an average 3.75 and 4.28 Mg ha⁻¹ during 2002 and 2003, respectively (Table 4.6). There was also neither a significant difference in root yield between the cassava monocrop and both intercrops in the short rainy season of 2003. However, root yields were significantly reduced by 0.50-0.57 Mg ha⁻¹ in maize-cassava intercrops during the short rainy season of experiment 02.

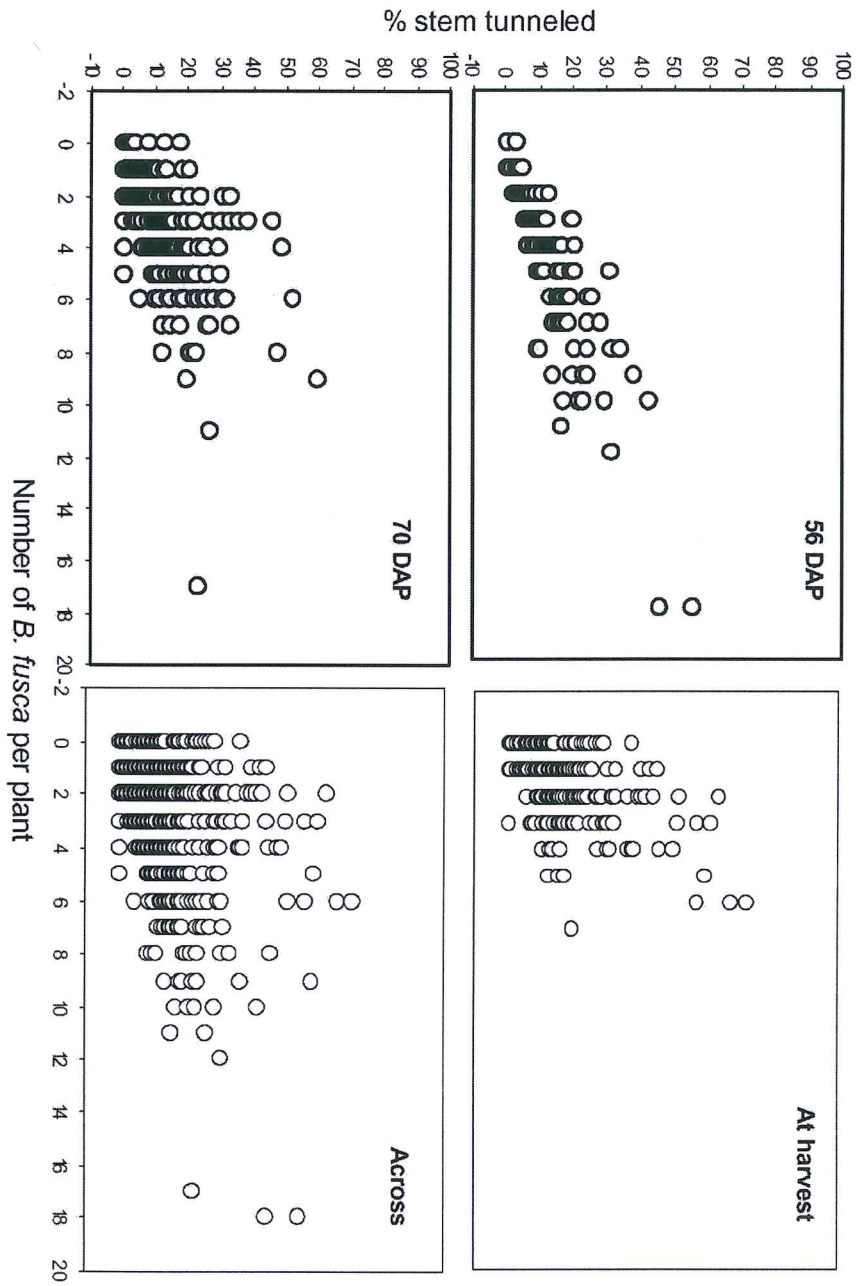


Fig. 4-1. The relationship between number of *Busseola fusca* per plant and percentage stem tunneled at different times after planting. DAP = days after planting. 56 DAP ($Y = -0.075 + 2.689 \times X$ with $r^2 = 0.88$, $P < 0.0001$), 70 DAP ($Y = 1.920 + 2.948 \times X$ with $r^2 = 0.48$, $P < 0.0001$), at harvest ($Y = 6.380 + 6.023 \times X$ with $r^2 = 0.35$, $P < 0.0001$), across DAP ($Y = 4.128 + 2.753 \times X$ with $r^2 = 0.31$, $P < 0.001$).

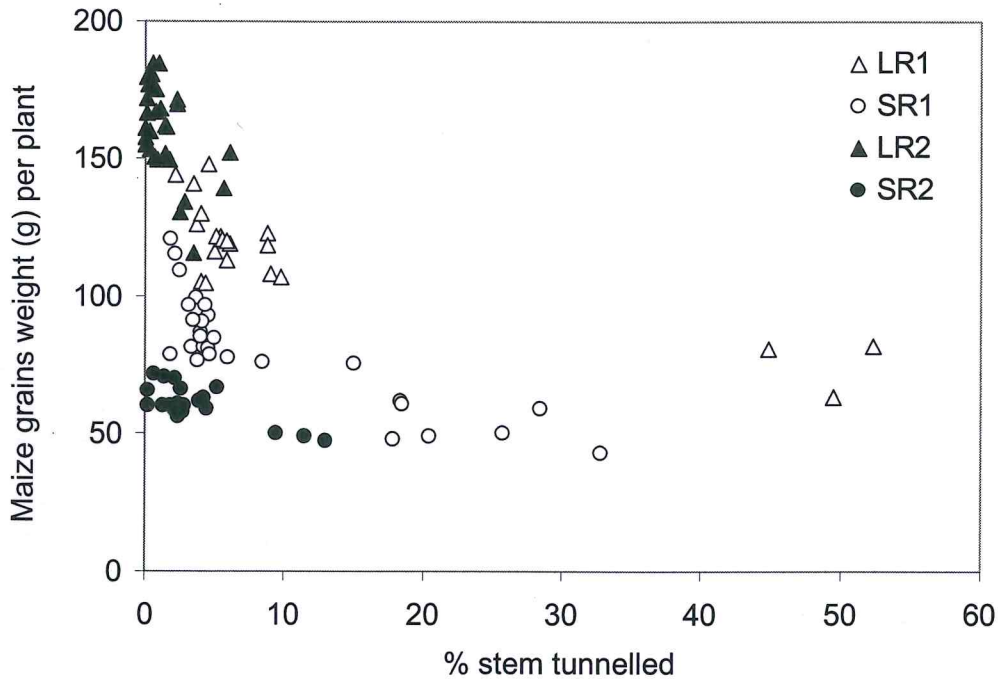


Fig. 4-2. Maize grain weight (g) per plant as a function of percentage stem tunnelling by borers, during the long (LR) and short (SR) rainy season of 2002 (1) and 2003 (2): LR1 ($Y = 127.80 - 1.099 \cdot X$ with $r^2 = 0.68$, $P < 0.0001$), SR1 ($Y = 96.87 - 1.840 \cdot X$ with $r^2 = 0.69$, $P < 0.0001$), LR2 ($Y = 169.57 - 5.389 \cdot X$ with $r^2 = 0.52$, $P = 0.0037$), and SR2 ($Y = 65.55 - 1.410 \cdot X$ with $r^2 = 0.54$, $P < 0.0001$).

Table 4.4. The relationship between maize grain yield and *Busseola fusca* per plant collected at different days after planting (DAP).

Variables	¹ b (+SE)	F	P-value	Average (+SE)
Y: Grain yield/plant (g)				106.82 (4.24)
X1: <i>B. fusca</i> /plant at 28-35 DAP	-32.88 (5.02)	42.92	< 0.0001	0.81 (0.06)
X2: <i>B. fusca</i> /plant at 42-49 DAP	-34.22 (4.43)	59.51	< 0.0001	0.95 (0.07)
Intercept = 166.156; $r^2 = 0.54$; n = 98				

Notes: stepwise multiple regressions, F values significant at $P \leq 0.15$, ¹b-values are partial regression coefficients.

Table 4.5. Least square mean of stem tunnelling (%), internodes bored (%) and cob damage (%) under different borer infestation levels in the different cropping patterns during the long and short rainy season of 2002 and 2003

Treatments	Growing season												
	Long rainy season						Short rainy season						
	Stem tunnelling		Internodes bored		Cobs damaged		Stem tunnelling		Internodes bored		Cobs damaged		
	IP	TP	IP	TP	IP	TP	IP	TP	IP	TP	IP	TP	
2002													
Maize-mono	44.2 aA	3.5 B	23.1 A	8.6 B	24.1 aA	3.0 B	25.5 aA	1.2 B	7.8 A	1.8 B	0.2	0.3	
Maize-cassava/Ah	5.3 bA	2.6 A	21.5 A	4.8 B	11.9 bA	2.7 B	3.5 cA	0.6 A	7.7 A	2.6 B	0.3	0.9	
Maize-cassava/Ar	6.8 bA	2.8 A	24.5 A	9.6 B	10.3 bA	4.0 B	3.7 cA	1.2 A	9.1 A	3.8 B	1.3	0.3	
Maize-cowpea/Ah	5.0 bA	1.8 A	15.6 A	6.0 B	7.9 bA	3.7 A	5.2 bCA	1.1 A	7.5 A	2.8 B	0.2	0.1	
Maize-cowpea/Ar	8.6 bA	2.0 B	16.9 A	6.4 B	10.8 bA	2.2 B	8.3 bCA	1.2 B	5.5 A	2.0 B	0.4	0.3	
Maize-soybean/Ah	7.7 bA	2.5 B	25.8 A	8.2 B	10.7 bA	5.6 A	7.2 bCA	0.7 B	9.3 A	3.0 B	0.7	1.0	
Maize-soybean/Ar	9.2 bA	3.0 B	21.3 A	9.0 B	11.2 bA	6.1 A	8.6 bA	0.6 B	7.5 A	1.6 B	0.8	0.7	
P-value	<0.001		<0.001		<0.001		<0.001		<0.001		0.079		
SE	1.76		2.90		2.08		2.19		1.31		0.42		
d.f.	42		42		42		42		42		42		
2003													
Maize-mono	1.4	0.3	3.1 A	0.8 B	2.1	0.8	11.3 aA	1.8 B	9.0	4.3	5.2 aA	0.3 B	
Maize-cassava/Ah	0.8	0.3	2.9 A	0.7 B	1.0	0.8	2.7 bA	1.5 A	3.1	8.9	4.1 aA	0.4 B	
Maize-cassava/Ar	0.6	0.1	2.6 A	0.5 B	1.6	0.4	3.3 bA	1.8 A	5.0	5.5	1.8 bA	0.3 B	
Maize-cowpea/Ah	1.7	0.3	3.8 A	0.5 B	2.5	0.6	2.6 bA	1.3 A	3.6	3.1	1.7 bA	0.7 A	
Maize-cowpea/Ar	0.8	0.1	2.2 A	0.8 B	1.9	0.7	2.5 bA	1.5 A	5.4	4.1	2.3 bA	0.6 B	
Maize-soybean/Ah	1.2	0.5	3.1 A	0.8 B	1.2	0.6	2.4 bA	1.0 A	6.2	4.2	2.0 bA	0.7 B	
Maize-soybean/Ar	1.2	0.5	2.9 A	1.2 B	1.3	0.9	2.7 bA	1.2 A	8.9	4.2	2.1 bA	0.9 A	
P-value	0.134		0.021		0.916		<0.001		0.162		<0.001		
SE	0.60		0.77		0.88		0.64		1.92		0.54		
d.f.	42		42		42		28		28		28		

Notes: IP, infested plot; TP, insecticide-treated plot. Within columns for a given experiment, means followed by the same lower case letter are not significantly different; within rows, means followed by the same capital letter are not significantly different (comparison between treated and non-treated plots for each cropping pattern) at $P < 0.05$ (t-test).

Legumes. Compared to monocrops, legume yields in intercrops were significantly lower by 0.27-0.38 Mg ha⁻¹ for cowpea and by 0.44-0.67 Mg ha⁻¹ for soybean in both experiments in 2002 and 2003 (Table 4.6). When planted in alternate rows, cowpea yielded with 0.15 and soybean with 0.17 Mg ha⁻¹ significantly more than those planted in alternate hills during the long rainy season of experiment 02 (Table 4.6). The same result was found in the long rainy season of 2003, albeit with lower yield differences of 0.08 and 0.11 Mg ha⁻¹, respectively. However, during the short rainy seasons of both experiments, cowpea yields did not differ between the two planting patterns, whereas soybeans in alternate rows yielded 0.06-0.12 Mg ha⁻¹ more than those in alternate hills (Table 4.6).

Land-use efficiency. Land-equivalent ratios (LER) and area-time equivalent ratios (ATER) for maize-cassava were consistently greater than 1.0 in all seasons and for both planting pattern (Table 4.7). They were considerably higher than those for maize-cowpea and maize-soybean in all seasons. The average of LER and ATER for both maize-grain legume intercrops was > 1.0 in the long and short rainy season of 2002 and in the short rainy season of 2003 for both, alternate hill and alternate row planting. In the long rainy season of 2003, the average of LER and ATER was slightly greater than 1.0 for alternate row planting of maize-cowpea and maize-soybean, but it was about 1.0 for alternate hill planting of both intercrops. The LER and ATER values of infested plots (IP) were consistently higher than those for plots treated with insecticide (TP) (Table 4.7).

The 'replacement values for intercrops' (RVI) was greater than 1.0 for all intercrops and all seasons, except for maize-soybean in the long rainy season of 2003. The RVI values of maize-cassava were about twice as high as those for maize-cowpea or maize-soybean.

Discussion

Busseola fusca diapauses as larvae during periods of food scarcity, thus, seasonal fluctuations of pest populations are strongly influenced by the amount and distribution of rainfall (Cardwell *et al.*, 1997; Ndemah *et al.*, 2000; Ndemah and Schulthess, 2002). In 2002, rains started early compared to 2003 and peaked in April and October vs. July and October in 2003 (chapter 3). Thus, very likely in

Table 4.6. Average dry matter yield (Mg ha⁻¹) of cassava roots and grain legumes monocropped or intercropped with maize in alternative hills (Ah) and alternative rows (Ar), during the long and short rainy season of 2002 and 2003

Treatments	Growing season					
	Long rainy season			Short rainy season		
	Cassava	Cowpea	Soybean	Cassava	Cowpea	Soybean
2002						
Monoculture	3.96	1.19	1.54	4.67	0.91	1.28
Maize-cassava/Ah	3.64	-	-	4.17	-	-
Maize-cassava/Ar	3.65	-	-	4.10	-	-
Maize-cowpea/Ah	-	0.77	-	-	0.60	-
Maize-cowpea/Ar	-	0.92	-	-	0.64	-
Maize-soybean/Ah	-	-	0.79	-	-	0.74
Maize-soybean/Ar	-	-	0.96	-	-	0.80
LSD	1.79	0.06	0.06	0.41	0.07	0.04
d.f.	21	21	21	21	21	21
2003						
Monoculture	4.49	0.90	1.07	4.31	0.88	1.15
Maize-cassava/Ah	4.12	-	-	4.16	-	-
Maize-cassava/Ar	4.22	-	-	3.91	-	-
Maize-cowpea/Ah	-	0.48	-	-	0.63	-
Maize-cowpea/Ar	-	0.56	-	-	0.59	-
Maize-soybean/Ah	-	-	0.47	-	-	0.65
Maize-soybean/Ar	-	-	0.58	-	-	0.77
LSD	0.62	0.06	0.07	0.71	0.07	0.06
d.f.	21	21	21	21	21	21

Notes: Yield data of the infested (IP) plots; LSD = least significant difference ($P < 0.05$).

Table 4.7. Land-equivalent-ratio (LER), area-time-equivalent-ratio (ATER) and 'replacement value' of the intercrop (RVI) of maize-cassava, maize-cowpea and maize-soybean intercrops, planted in alternative hills (Ah) or alternative rows (Ar), during the long and short rainy season of 2002 and 2003

Treatment	Growing season													
	Long rainy season					Short rainy season								
	LER		ATER		Average	LER		ATER		Average	RVI			
IP	TP	IP	TP	IP	TP	IP	TP	IP	TP	IP	TP	RVI		
2002														
Maize-cassava/Ah	1.72	1.48	1.29	1.18	1.51	1.33	2.14	1.77	1.51	1.30	1.17	1.54	1.34	2.26
Maize-cassava/Ar	1.67	1.41	1.27	1.15	1.47	1.28	2.12	1.66	1.41	1.24	1.12	1.45	1.27	2.18
Maize-cowpea/Ah	1.30	1.13	1.18	1.02	1.24	1.08	1.39	1.35	1.11	1.23	0.99	1.29	1.05	1.13
Maize-cowpea/Ar	1.47	1.26	1.33	1.12	1.40	1.19	1.61	1.37	1.16	1.24	1.04	1.31	1.10	1.15
Maize-soybean/Ah	1.26	1.01	1.26	1.00	1.26	1.01	1.23	1.29	1.05	1.29	1.05	1.29	1.05	1.08
Maize-soybean/Ar	1.32	1.14	1.32	1.14	1.32	1.14	1.36	1.35	1.14	1.35	1.14	1.35	1.14	1.13
2003														
Maize-cassava/Ah	1.47	1.46	1.17	1.16	1.32	1.31	2.00	1.68	1.52	1.29	1.22	1.49	1.37	3.56
Maize-cassava/Ar	1.46	1.45	1.18	1.17	1.32	1.31	1.98	1.58	1.45	1.22	1.15	1.40	1.30	3.34
Maize-cowpea/Ah	1.06	1.05	0.96	0.96	1.01	1.01	1.02	1.32	1.18	1.19	1.05	1.26	1.12	1.81
Maize-cowpea/Ar	1.14	1.11	1.02	1.00	1.08	1.06	1.09	1.30	1.15	1.18	1.03	1.24	1.09	1.74
Maize-soybean/Ah	0.98	0.97	0.98	0.97	0.98	0.97	0.92	1.16	1.03	1.16	1.03	1.16	1.03	1.54
Maize-soybean/Ar	1.07	1.05	1.07	1.05	1.07	1.05	0.97	1.31	1.18	1.31	1.18	1.31	1.18	1.76

Notes: Average = (LER + ATER)/2, IP, infested plot; TP, insecticide-treated plot.

2002, *B. fusca* terminated diapause earlier resulting in a faster build-up of pest populations compared to 2003, thereby causing high yield losses during the first season of 2002. Likewise, severity of borer damage, as evidenced by the % stem tunneled and % cob damaged, was directly proportional to numbers of attacking larvae. Differences in the population of insects in crops may be due to initial differences in the number of arrivals (Southwood and Way, 1970; Adesiyun, 1979) or to different rates of multiplication in the crop as well as mortality rates (Way and Heathcote, 1966; Smith, 1976). In the present study, the temporal fluctuation of larval infestations in intercrops more or less followed that of the monocrop, but densities were considerably lower in mixed cropping systems. Similarly, Schulthess *et al.* (2004) showed that the numbers of *S. calamistis* egg batches were consistently lower on inter- compared to monocropped maize. They concluded that, the presence of the non-host plants reduced the host finding ability of the ovipositing female moths. This was corroborated for *B. fusca* (see chapter 3). Furthermore, young *B. fusca* larvae move from the oviposition site between the leaf sheath and the stem to the whorl from where they either penetrate into the stem or disperse to other plants (Kaufmann, 1983). Thus, van Rensburg *et al.* (1988) reported that maize plant density had a significant effect on the extent of yield losses caused by *B. fusca* due to the tendency of the larvae to migrate to neighboring plants. Hence, in mixed cropping with non-host plants, migration-related mortality of young larvae should be expected to be higher as a result of reduced host finding. However, in the present experiments differences in egg-to-larva mortalities between cropping patterns were not significant. Consequently, most of the differences in larval densities found in the present experiments were due to differences in oviposition rates rather than migration-related mortality, corroborating results by Schulthess *et al.* (2004) for *S. calamistis* in a cassava-maize intercrop.

Differences in larval densities among treatments were higher during the vegetative than reproductive stages of maize, and no significant difference was found at harvest. At that time, most borers had reached adulthood and had hatched, indicating that larval counts at harvest are not a reliable indicator of the extent of infestation that occurred during the crop cycle. The lack of relationship between numbers of *B. fusca* at harvest and yield and the strong negative relationship between stem tunnelling and yield shows that the proportion of stem

tunnelling is a far more reliable indicator of yield loss due to number of pests. This was confirmed by several authors for various African stem borer species (Bosque-Pérez and Mareck, 1991; Gounou *et al.*, 1994; Sétamou *et al.*, 1995; Ndemah *et al.*, 2000; Songa *et al.*, 2001).

The maize grain yield per plant was significantly negatively related to the number of larvae found at the vegetative stage of plant growth. Thus, larval counts made during the vegetative growth of the maize plants are a reliable predictor for the extent of yield losses at harvest.

Our findings showed that LER was higher than ATER in all the cropping patterns. According to Mason *et al.* (1986), LER overestimates and ATER underestimates the land use efficiency. Thus, they suggested to average LER and ATER to provide a more accurate estimate of the land use efficiency. In the present study, maize-cassava intercrops had a 46-77 % greater land use efficiency as compared to sole cropping, across all seasons. Cassava is one of the most important sources for carbohydrates in SSA (FAO, 1999). In southern Cameroon, cassava is an important component of most farming systems and the major staple food of the rural and urban poor (Ndemah, 1999). The considerably greater land-use efficiency of a maize-cassava intercrop, and especially in insecticide treated plots, is of paramount importance for land-constrained and poor farmers. The early crops, maize or legumes, are harvested after 3-4 months while the cassava harvest may start as early as 9 months after planting but the bulk of cassava is harvested after 12-35 months (Mutsaers *et al.*, 1993). As shown by Schulthess *et al.* (2004) the later the crop is harvested the smaller the differences in yield between mono- and intercropped cassava. Thus, in the present experiment, cassava was harvested at one year after planting and the crop had ample time to recover from the stresses of interspecific plant competition incurred at the beginning of the crop cycle and finally produced similar yields in both mono- and intercrops. Thus, without input, such as fertilizers and pesticides, maize is better grown in a mixed system with cassava, irrespective of the planting pattern. The net production of such a system is considerably higher than sole maize cropping with furadan treatment, as demonstrated by highly positive RVI values (Table 4.7). However, according to Mutsaers *et al.* (1993), high maize yields in maize cassava intercrops of above 3.5 Mg ha⁻¹, lead to increasingly negative effects on cassava root yields, if cassava is harvested early. This means that intensive intercropping

with fertilizer input might increasingly lose its advantage vis-à-vis sole cropping. This was also the trend in our trials, where higher crop yields in the long rainy season of 2003 had much lower RVI values than lower crop yields in the short rainy season of 2003. At present it is not possible to determine at what yield (and price) level of maize and cassava and at what level of *B. fusca* infestation, intercropping is no longer preferable to sole cropping. This would require further experiments.

Intercropping maize with cowpea and soybean resulted in lower LER and RVI values than with cassava. In all four seasons, both grain legumes had a similar effect on stemborer infestations and maize yields tended to be as high as in the maize-cassava intercrops. Thus, lower grain legume yields in the intercrop relative to its sole crop caused a lower land-use efficiency and net productivity. Thus, cowpea yields were reduced by about 30 % in the intercrop and soybean yields by about 40 % (Table 4.5). In contrast to cassava, both maize and grain legumes have a phasic growth pattern and take 3-4 months to maturity. In addition, cassava uses reserves from cuttings for its initial growth. It is, therefore, not surprising that the competition for resources is higher among short-duration crops than between short-duration crops and cassava. In such systems, the C4 plant maize is more competitive than the C3 plants cowpea and soybean (Ofori and Stern, 1987) and a high LER is obtained when the dominated species produces a high partial LER, while the other component has a partial LER of close to 1.0 (Fukai and Trenbath, 1993). Thus, Härdter *et al* (1991) increased LER and ATER of a maize-cowpea intercrop considerably through fertilizer application in low input systems in Northern Ghana. However, the opposite was found by Ofori and Stern (1986) in highly intensive systems in Western Australia.

Conclusion

Intercropping maize with non-host plants substantially reduces stem borer infestation of maize in southern Cameroon. In three out of four seasons the yield loss of maize was 50 % to 67 % lower in the intercrop. This was mainly a result of reduced oviposition rather than migration-related mortality of *B. fusca*.

All intercropping systems had the additional advantage that land productivity was higher than with sole maize cropping. The maize-cassava crop was the most

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efficient in terms of land use and the most productive vis-à-vis sole maize with insecticide application. At medium intensity or crop yields this system is thus recommendable for land-constrained poor farmers who do not use external inputs such as fertilizer.

Effects of Grain Legumes and Cover Crops on Maize Yield and Plant Damage by *Busseola fusca* (fuller) (Lepidoptera: Noctuidae) in the Humid Forest of Southern Cameroon^c

Abstract

Field trials were run in the humid forest zone of Cameroon to investigate the effects of crop rotation, cover crops and bush fallow on infestations by the noctuid stemborer *Busseola fusca* (Fuller) and on yield of maize. A continuous maize production system was compared with crop sequence systems, in which maize followed a grain legume (cowpea, soybean), cover crop (mucuna, peagon pea) or a bush fallow. Compared to the continuous maize cropping system, maize in the crop sequence with legume and fallow systems had a significantly higher leaf and stem nitrogen content at 35 and 63 days after planting (DAP), respectively. Differences in K and P at 35 and 63 DAP, and of N in stem and grain at harvest were not significant. Maize in the rotation systems had 1.5-2 times more borers per plant compared to the continuous maize production systems, particularly at the early stages of maize growth. At 63 DAP, larval mortalities were 1.4-1.5 higher in rotation systems than in the continuous maize system. As a result, dead-hearts and tunnel length did not vary significantly among treatments. In the insecticide protected plots, when comparing with the maize-maize cropping system, average grain yields were increased by 15.1-24.6 % and 30.3-42.5 % in crop sequences of grain legumes with maize and cover crops fallow systems, respectively. However, grain yield losses due to borers were 1.9-3.1 times higher in the continuous maize production system than in the crop sequences of grain legumes with maize and 4.5-11.1 times higher compared to maize after cover crops. It is concluded that an

^c Published as Chabi-Olaye, A., Nolte, C., Schulthess, F. and Borgemeister, C. (2005) Effects of grain legumes and cover crops on maize yield and plant damage by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in the humid forest of southern Cameroon. *Agriculture, Ecosystems and Environment* (in press).

increased nutritional status of the plants lead to an increase in borer attacks at the early stage of plant growth, but also to improved plant vigour, resulting finally in a net benefit for the plant and grain yield.

Introduction

Maize is one of the most important sources for carbohydrates in sub-Saharan Africa (SSA) (FAO, 2001). In Cameroon, maize is grown across all agro-ecological zones, from sea level to the highlands at 2,000 m a.s.l., and it is still expanding to new ecozones such as the humid forest. Maize yields in Cameroon increased during 1993 to 2002, from 1.13 to 2.50 Mg ha⁻¹ (FAOSTAT, 2002), which is still considerably less than the 4.3 Mg ha⁻¹ world-average. The major biotic constraints for maize production in the forest zone of Cameroon, besides termites, birds, the cane rat and weeds, are lepidopterous stemborers such as the noctuid *Busseola fusca* (Fuller) and the pyralid *Eldana saccharina* (Walker) and low soil fertility (Hauser & Nolte, 2002; Hauser *et al.*, 2002; Nolte *et al.*, submitted); they lead to a reduction in quality and quantity of pre- and post-harvest maize (Bosque-Pérez & Mareck, 1991; Cardwell *et al.*, 1997; Schulthess *et al.*, 1997; Sétamou *et al.*, 1998, 2000a; Ndemah, *et al.*, 2001a).

Variations in the availability of soil nutrients can influence the susceptibility of plants to pests and diseases (Haseman, 1946). Numerous studies showed the effects of nutrients, such as nitrogen and potassium, on borer incidence in cereals such as rice (Saroja *et al.*, 1987; Thakar & Mishra, 1989; Sharma & Reddy, 1991; MacLean *et al.*, 2003), maize (Archer *et al.*, 1987; Martin *et al.*, 1989; Sétamou *et al.*, 1993, 1995; Sétamou & Schulthess, 1995; Ndemah, 1999; Denké *et al.*, 2000) and sugar cane (Atkinson & Nuss, 1989). In most of the experiments, mineral fertilizer was used.

During the past two decades several leguminous cover crops such as *Mucuna pruriens* (L.) DC. varieties, *Pueraria phaseoloides* (Roxb.), *Cajanus cajan* (L.) Millsp. and *Canavalia ensiformis* (L.) DC., to name but a few, have been tested in SSA. Their role in improving soil fertility properties and controlling weeds is widely documented (Vissoh *et al.*, 1998; Carsky *et al.*, 2001; Tian *et al.*, 2001). Short-duration fallows with cover crops and grain legumes have shown to considerably increase succeeding maize yields (Balasubramanian & Nguimgo,

1993; Horst & Härdter, 1994; Ile *et al.*, 1996; Carsky *et al.*, 1998). Maize grain yields of $> 4 \text{ Mg ha}^{-1}$ were obtained in southern Cameroon after a short-term fallow with mucuna (Hauser & Nolte, 2002). Consequently, there is a tremendous potential for farmers in West and Central Africa to integrate leguminous cover crops into their cropping patterns. However, no information is available on the short-term effects of cover crops or grain legumes on maize pests. Thus, field trials were set up to assess the effect of maize-legume cropping sequences and continuous maize cropping on both stemborer infestations and yield of maize. In our study, emphasis was given to *B. fusca*, which is the economically most important maize pest in the region (Cardwell *et al.*, 1997; Ndemah *et al.*, 2001a, 2003; Ndemah & Schulthess, 2002).

Materials and Methods

Experimental site

Experiments were conducted from March 2002 to January 2004 at Nkometou ($4^{\circ} 05'N$, $11^{\circ} 33'E$), a village 40 km west of Yaoundé. The trials were laid out in a 3-4 year-old bush fallow, dominated by *Chromolaena odorata* (L.) R. M. King & H. Rob. (Asteraceae), on a Rhodic Kandiudilt soil. The chemical analysis of the top soil (0-20 cm) revealed a bulk density of $1.10\text{-}1.25 \text{ g cm}^{-3}$, a $\text{pH}(\text{H}_2\text{O})$ of 5.6, 0.13 % total N, 1.85% organic carbon, $11.3 \mu\text{g g}^{-1}$ available P (Mehlich-III extract), and $0.23 \text{ cmol}(+) 100 \text{ g}^{-1}$ of exchangeable K. The site is characterized by a bimodal distribution of rainfall, with peaks in June and September and an annual precipitation of about 1,500 mm. The first and second growing seasons (herewith referred to as long and short rainy season, respectively) last typically from mid March to mid July and from mid August to end of November, respectively. A short dry spell of about four weeks occurs in July. The major dry season starts in the third week of November and lasts through end of February or beginning of March.

Experimental procedure

Two field trials were set up. In experiment I, grain legumes preceded maize in either the long or short rainy seasons, while in experiment II, it was leguminous cover crops or bush fallow followed by maize. In both experiments, the cropping sequences were compared with a maize-maize sequence. The field of experiment

I had also been used for an intercropping trial with, among other, grain legumes in pure stands prior to running the present experiment. Two grain legumes were selected, i.e., soybean *Glycine max* (L.) Merr. (TGX 1838-5E) and an erect cowpea *Vigna unguiculata* (L.) Walp. var. Asonten (both Fabaceae). In experiment II, two species of cover crops were used i.e., *M. pruriens* var. jaspeada and *C. cajan* (local var.). In the long-short rainy season (LSR) sequence, cover crops were planted between 15-30 March and left to grow from March to August of the same year, thus covering the long rainy season. The succeeding maize crop was sown between 5-15 September of the same year. In the short-long rainy season (SLR) sequence, which lasts from September to August in the next year, cover crops were planted between 5-15 September and the succeeding maize between 15-30 March. The grain legumes were generally planted one or two weeks after the cover crops.

Each experiment had a control plot with an insecticide treatment. The treatments were arranged in a completely randomised block design with four replications. Plots were 6 by 6 m each. The four blocks were established at a distance of 150-200 m from each other to reduce interactions between treatments. The distance between plots within a block was 1.5 m.

Mucuna was planted at 25 by 50 cm distance (8 grains m⁻²) and *cajanus* at 50 by 50 cm (8 plants m⁻²). The grain legumes, i.e. soybean and cowpea, were planted at 75 by 10 cm and 75 by 25 cm, respectively, and thinned to two plants per hill at 14 DAP.

The cover crops were cut about four to five weeks before planting of the succeeding maize crop, and their biomass retained on the plots without incorporation into the soil. All maize planting was done at a spacing of 75 cm between rows and 50 cm within rows. Four seeds of 110-days open pollinated maize cv. Cameroon Maize Series (CMS) 8704 were sown per hill and the stands thinned to two plants per hill 14 DAP. Plots were weeded at 14 and 35 DAP. Insecticides were applied to maize 21 and 42 DAP using carbofuran at ca. 1.5 a.i. kg ha⁻¹ by placing the granules in the whorl.

Plant and soil analyses

For plant nutrient analyses, four plants were randomly taken from each plot. Fresh biomass samples were oven-dried at 65°C until constant weight. The dried

samples were ground to pass a mesh of 0.5 mm and their N concentration determined. Samples were digested according to Novozamsky *et al.* (1983). Total N was determined with an ammonium sensitive electrode (Powers *et al.*, 1981). The N contents of leaves and stems were measured at 35 and 63 DAP, and of stems, in addition, at harvest together with that of the cobs.

Soil sampling was done prior to planting of the succeeding maize. Each plot was divided into four quadrants. Five samples were taken at 0-10 and 10-20 cm depth from each quadrant along with one sample from the centre in each plot, resulting in a total of 10 samples per plot.

Soil samples were air-dried and ground to pass a 2 mm mesh. Cations (Ca, Mg, K) and P were extracted by the Mehlich-3 procedure (Mehlich, 1984). Soil pH was determined in water at a 2:5 soil solution ratio. Organic C was determined by chromic acid digestion and spectrophotometric procedure (Heanes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner & Tabatabai, 1972; Nelson & Sommers, 1972).

Pest numbers, plant damage and yield

Twelve plants per plot were sampled destructively every two weeks. Plants were only sampled from the centre 5 by 5 m sub-plot. Data recorded in insecticide-free plots were plant height, the number of borers, plant damage variables, i.e. number of nodes and internodes bored, an estimate of borer tunnel length, percentage of plants with dead-heart symptoms and of plants with whorl damage.

Twenty-four plants were sampled per plot at harvest. The feeding damage of borers was estimated as the percentage of grains consumed, using a one to five rating scale (scale: 1 = 0-5 %; 2 = 6-25 %; 3 = 26-50 %; 4 = 51-75 %; 5 = 76-100 % grains damage) developed by Bosque-Pérez and Mareck (1991). The dry matter content of plant components (leaves, stems, cobs, and dry weight of grains) was assessed. The grain yield was recorded for each plot. For this, each plot was divided into four quadrants, and a predetermined sub-plot of 1 m² was harvested per plot. Plants were counted, and cobs were removed, husked and weighed. A subsample of 4 cobs per quadrant was weighed, dried at 65 °C, the dry grain removed and weighed again to determined grain dry matter yield.

Statistical analyses

The analyses were done separately for each cropping season. Differences in plant height, total dry matter, grain weight, and damage variables were analysed by analysis of variance (ANOVA), using the general linear model (GLM) procedure of SAS (SAS, 1997). LSD values at 5 % significant level were computed. The mixed model (Proc mixed) of SAS (SAS, 1997) with repeated measures was used to determine the variation in *B. fusca* abundance over sampling days. The treatments were considered as fixed effects, while plants within replications were considered as random factor. Least squares means (LSM) were separated using the t-test. The significance level was set at $P = 0.05$.

Correlation coefficients were calculated using data pooled across seasons and treatments. Correlations and regressions calculated over all plots could be misleading, however, because of differences due to seasonal sequences. Thus, a covariance analysis of grain yield was carried out, using plant damage variable as covariates.

Results*Cropping sequence and fallow effects on the nutrients status of the soil and the subsequent maize crop*

P and K concentration in the 0-20 cm depth did not vary significantly among treatments whereas the total N content in the 0-10 cm layer differed significantly among cropping systems (Table 5.1); it was 1.4-1.5 times higher in the crop sequences and fallow treatments than in the continuous maize systems and 1.1-1.2 times higher after natural fallow than in the sequential maize production system (Table 5.1).

Table 5.1. Total N content (%), P ($\mu\text{g g}^{-1}$) and K ($\text{cmol (+)} 100 \text{g}^{-1}$) concentration in the 0-10 and 10-20 cm layers after natural regrowth, grain legumes and cover crops fallow.

Treatments	Seasonal sequence											
	LSR ¹⁾						SLR ²⁾					
	N		P		K		N		P		K	
	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
Experiment I												
Maize-maize	0.131	0.096	15.09	2.79	0.202	0.089	0.138	0.094	18.92	3.38	0.251	0.099
Cowpea-maize	0.177	0.098	14.84	2.51	0.199	0.090	0.185	0.097	17.34	2.93	0.250	0.098
Soybean-maize	0.187	0.095	15.84	2.55	0.192	0.086	0.199	0.100	19.34	3.15	0.222	0.092
P-value	<0.001	0.929	0.815	0.669	0.790	0.905	<0.001	0.776	0.644	0.617	0.422	0.842
LSD	0.017	ns	ns	ns	ns	ns	0.014	ns	ns	ns	ns	ns
d.f. ³⁾	21	9	21	9	21	9	21	9	21	9	21	9
Experiment II												
Maize-maize	0.148	0.090	15.50	3.12	0.312	0.128	0.145	0.097	20.47	4.53	0.300	0.095
Bush-maize	0.175	0.105	16.04	4.86	0.429	0.139	0.166	0.102	19.29	4.36	0.329	0.112
Cajanus-maize	0.199	0.107	17.74	3.85	0.463	0.152	0.205	0.108	20.85	4.32	0.310	0.105
Mucuna-maize	0.208	0.103	18.78	4.43	0.441	0.129	0.219	0.109	20.38	3.82	0.291	0.107
P-value	<0.001	0.377	0.728	0.231	0.293	0.656	<0.001	0.823	0.977	0.764	0.895	0.808
LSD	0.015	ns	ns	ns	ns	ns	0.017	ns	ns	ns	ns	ns
d.f. ³⁾	60	28	60	28	60	28	28	12	28	12	28	12

Notes: 1) long-short rainy season sequence; 2) short-long rainy season sequence; 3) degrees of freedom in the F-test; ns, not significant.

The N content in leaves and stem at 35 and 63 DAP differed significantly among treatments (Table 5.2). By contrast, there were no differences in grain and stem N-concentrations at harvest. N in the leaves and stem were, respectively, 1.1 and 1.3 times higher in the long than short rainy season. In both experiments, it was 1.2-1.4 times higher in the fallow systems than in the continuous maize systems (Table 5.2).

Table 5.2. Means of N content (%) in the dry matter of plant components at 35, 63 DAP and at harvest of maize in different fallow and rotation systems (experiment I and II, respectively)

Treatments	Seasonal sequence							
	LSR ¹⁾				SLR ²⁾			
	35 DAP ³⁾	63 DAP	Harvest		35 DAP	63 DAP	Harvest	
	Leave	Stem	Stem	Grain	Leave	Stem	Stem	Grain
Experiment I								
Maize-maize	1.469	0.428	0.191	-	1.527	0.515	0.242	-
Cowpea-maize	1.743	0.502	0.215	-	1.918	0.658	0.225	-
Soybean-maize	1.820	0.560	0.233	-	2.098	0.725	0.264	-
<i>P</i> -value	0.027	0.001	0.700		0.032	<0.001	0.166	
LSD	0.251	0.063	ns		0.361	0.053	ns	
d.f.	12	21	21		12	21	12	
Experiment II								
Maize-maize	1.357	0.396	0.256	1.276	1.393	0.544	0.243	1.510
Bush-maize	1.607	0.433	0.202	1.297	1.655	0.591	0.244	1.449
Cajanus-maize	1.907	0.488	0.199	1.300	1.938	0.691	0.268	1.535
Mucuna-maize	1.981	0.613	0.261	1.344	2.623	0.769	0.296	1.706
<i>P</i> -value	<0.001	<0.001	0.453	0.723	0.003	<0.001	0.486	0.190
LSD	0.143	0.064	ns	ns	0.38	0.102	ns	ns
d.f.	12	12	28	28	12	28	20	12

Notes: ¹⁾ long-short rainy season sequence; ²⁾ short-long rainy season sequence; ³⁾ DAP = days after planting.

Cropping sequence and fallow effects on the abundance of stem borers

Busseola fusca larval densities varied significantly with DAP in both experiments (linear trend between 35 and 77 DAP, $P < 0.001$). In the first set of experiments, where maize was planted during LSR, *B. fusca* densities decreased gradually in all treatments from 33 to 77 DAP (Table 5.3). When maize was planted during SLR, borer densities tended to be highest at 49 DAP.

Differences in pest densities tended to be significant during the first 49 days only. The number of *B. fusca* varied significantly with cropping sequence. They were higher after soybean than after cowpea, and higher after both leguminous cover crops than after natural fallow (Table 5.3).

Larval densities were 1.2-1.5 times higher in the long than short rainy season and in both experiments, 1.5-2 times higher in the crop sequences than in the continuous maize systems (Table 5.3).

Cropping sequence and fallow effects on plant damage variables

In both experiments the percentage of plants with window damage followed the same trends as the numbers of *B. fusca*. At 49 DAP, it was 1.4-1.9 times higher after leguminous fallow than in maize following maize (Table 5.4). Dead-hearts and average tunnel length did not vary significantly among treatments. In all treatments of both experiments tunnel length varied considerably and significantly between insecticide-treated and non-treated plots. Ear damage was very low (< 1.2 on the 1 to 5 scale) and the results are not shown here. Overall, plant damage was higher after leguminous fallow trial than after grain legume rotation.

Cropping sequence and fallow effects on plant growth variables and yield loss

Plant height changed significantly with DAP ($P < 0.001$) in both experiments. It was faster in the fallow systems than in the continuous maize production system (Fig. 5-1). The difference in plant height in experiment I was already apparent among treatments at 35 DAP, where the average plant height of maize after mucuna was 1.4 times higher than that of maize following maize. Thereafter, the

Table 5.3. Effects of different fallow and rotation systems (experiment I and II, respectively) on the abundance of *Busseola fusca* (Least square means) on the maize planted during the short and long rainy season (LSR, SLR, respectively).

Treatments	Seasonal sequence							
	LSR ¹⁾			SLR ²⁾				
	35 DAP ³⁾	49 DAP	63 DAP	77 DAP	35 DAP	49 DAP	63 DAP	77 DAP
Experiment I								
Maize-maize	1.33 cA	0.56 B	0.23 C	0.19 C	1.37 cB	1.69 bA	0.92 C	0.27 D
Cowpea-maize	1.77 bA	0.62 B	0.19 C	0.21 C	2.12 bB	2.52 aA	1.12 C	0.31 D
Soybean-maize	2.17 aA	0.73 B	0.31 C	0.12 C	2.46 aA	2.75 aA	1.21 B	0.33 C
SE	0.09				0.12			
d.f.	33				33			
Experiment II								
Maize-maize	1.11 cA	0.92 bAB	0.64 BC	0.52 C	1.17 bB	1.58 cA	1.10 B	0.67 C
Bush-maize	1.58 bA	1.41 aA	0.67 B	0.60 B	2.01 aA	2.50 bA	1.01 B	0.50 B
Cajanus-maize	2.01 aA	1.58 aB	0.69 C	0.51 C	2.33 aA	2.89 abA	1.21 B	0.58 C
Mucuna-maize	2.19 aA	1.54 aB	0.77 C	0.56 C	2.48 aB	3.29 aA	1.19 C	0.69 C
SE	0.12				0.18			
d.f.	109				45			

Notes: Within column, means followed by the same lowercase letter are not significantly different at $P < 0.05$ (t-test). Within row, means followed by the same capital letter are not significantly different at $P < 0.05$ (difference between DAP); ¹⁾ long-short rainy season sequence; ²⁾ short-long rainy season sequence; ³⁾ DAP = days after planting.

Table 5.4. Effects of different fallow and rotation systems (experiment I and II, respectively) on the damage caused by *Busseola fusca* to maize

Treatments	Seasonal sequence							
	LSR				SLR			
	Window damage at 49 DAP(%)	Dead heart at 56 DAP(%)	Stem tunnel (cm)		Window damage at 49 DAP(%)	Dead heart at 56 DAP(%)	Stem tunnel (cm)	
			IP	CP			IP	CP
Experiment I								
Maize-maize	19.2 c	2.5	4.90 A	0.82 B	23.7 c	3.6	8.10 A	1.22 B
Cowpea-maize	21.7 b	2.3	6.01 A	0.87 B	32.4 b	3.8	9.07 A	1.32 B
Soybean-maize	33.2 a	2.6	4.75 A	1.05 B	42.0 a	3.2	7.17 A	1.07 B
SE	0.65	0.2	1.14		0.76	0.23	1.25	
d.f.	21	21	18		21	21	18	
Experiment II								
Maize-maize	21.0 d	3.6 b	8.41 A	1.29 B	30.9 d	4	19.47 A	0.90 B
Bush-maize	24.3 c	5.2 a	9.01 A	1.52 B	35.4 c	3.8	14.27 A	0.30 B
Cajanus-maize	35.3 b	5.5 a	10.35 A	1.44 B	53.7 b	3.9	17.80 A	0.53 B
Mucuna-maize	39.1 a	5.7 a	9.96 A	1.72 B	57.7 a	4.4	16.20 A	1.07 B
SE	0.84	0.39	1.61		0.87	0.4	3.78	
d.f.	44	44	56		20	27	16	

IP= infested plot, CP= controlled plots with furadan; DAP, days after planting. Within column, means followed by the same lower case letter are not significantly different at $P < 0.05$ (t-test). Within row, means followed by the same capital letter are not significantly different at $P < 0.05$ (differences between IP and CP).

differences increased until harvest. No significant differences were found among treatments up to 35 DAP ($F = 0.63$, $d.f. = 182$, $P = 0.597$) in experiment II. However, at 49 DAP the plant height of maize after maize was significantly lower than in the other treatments ($P < 0.001$).

The average plant height at harvest was reduced by 2-8 % and total dry matter by 8.5-23 % in the insecticide-protected plots, in both experiments, when comparing between unprotected plants and insecticide-treated plants. By contrast, the average plant height of maize following maize was reduced by 8-16.7 % and its total dry matter by 26-47.5 % as compared to that of maize after fallow.

Grain yields differences between continuous maize and crop sequences were between 15.1-24.6 % in experiment I, and 30.3-42.5 % in experiment II higher in crop sequences than in the continuous maize (Table 5.5). In experiment I during

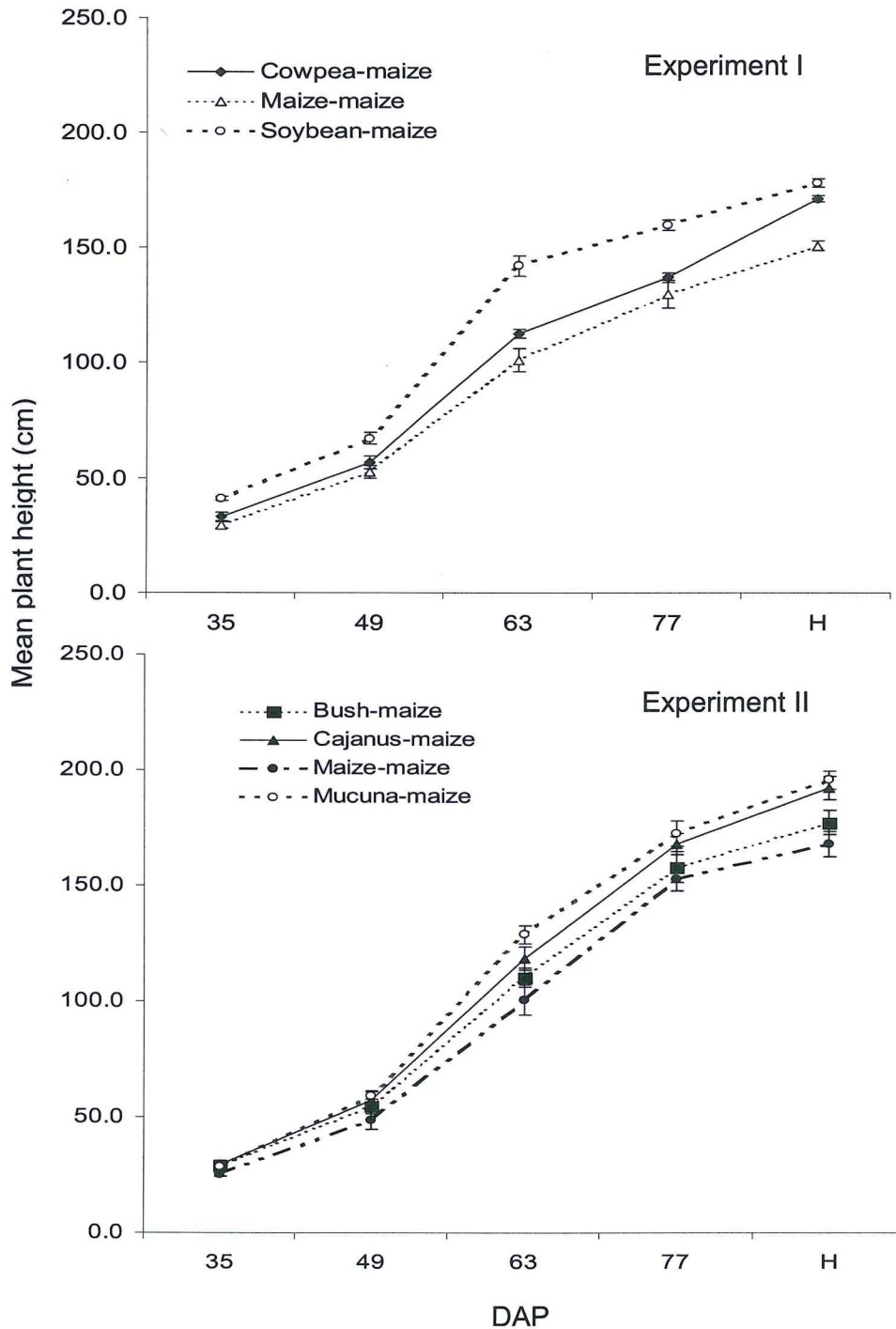


Fig. 5-1. Maize plant height subjected to different fallow systems at different days after planting (DAP).

Effect of Crop Sequences on *Busseola fusca* and Maize Yield

Table 5.5. Effects of different fallow and rotation systems (experiment I and II, respectively) on plant growth variables and grain yields with the maize crop planted during the short and long rainy season (LSR, SLR, respectively).

Treatments	Seasonal sequence													
	LSR						SLR							
	Plant height cm per plant	Dry matter g per plant	Grain weight g per plant	Yield loss (%)	Plant height cm per plant	Dry matter g per plant	Grain weight g per plant	Yield loss (%)	Plant height cm per plant	Dry matter g per plant	Grain weight g per plant	Yield loss (%)		
Experiment I	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP		
Maize-maize	149.5	165.8	87.8	104.0	40.8	50.6	19.4	199.1	216.2	152.0	174.6	61.9	78.3	20.9
Cowpea-maize	170.6	186.6	121.2	151.2	49.5	59.6	16.9	243.4	255.9	210.6	227.1	84.5	96.6	12.5
Soybean-maize	177.9	193.5	126.4	155.7	63.8	65.8	3.0	252.3	263.4	222.4	237.0	99.9	103.8	3.8
Maize-m-cowpea fallow (%) ^a					17.6	15.1						26.7	18.9	
Maize-m-soybean fallow (%) ^a					36.1	23.1						38.0	24.6	
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD (5%)	12.2	19.6	19.6	4.7	6.2	8.1	5.9	6.2	8.1	8.1	5.9	5.9	5.9	5.9
d.f.	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Experiment II														
Maize-maize	156.8	164.5	118.8	130.0	43.5	54.7	20.5	178.8	188.2	167.3	191.0	54.5	71.1	23.3
Bush-maize	176.4	180.9	142.0	185.5	66.4	72.0	7.8	188.7	210.5	176.5	234.9	88.5	100.5	12.0
Cajanus-maize	171.0	175.0	138.1	171.6	74.8	78.5	4.7	213.1	213.5	258.3	339.4	108.2	112.6	3.9
Mucuna-maize	171.1	181.6	143.7	186.5	85.3	88.9	4.0	220.5	225.0	284.2	364.0	120.4	123.6	2.6
Continuous-bush fallow (%) ^a					34.5	24.0						38.4	29.2	
Maize-m-cajanus fallow (%) ^a					41.8	30.3						49.6	36.9	
Maize-m-mucuna fallow (%) ^a					49.0	38.5						54.7	42.5	
P-value	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0487	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD (5%)	9.5	17.0	17.0	8.9	8.9	13.8	2.6	32.0	40.8	40.8	13.8	13.8	13.8	13.8
d.f.	24	24	24	24	24	24	24	16	16	16	16	16	16	16

IP= infested plots, CP= controlled plots with furadan; %yield loss = (CP-IP/CP)*100; ^a Percentage difference between the maize-maize and the fallow or rotation treatment.

both seasons the lowest yields were recorded in the continuous maize treatment. The highest yields were found in the soybean-maize treatments. In experiment II, the lowest grain yield was found in maize after maize and the highest in maize after mucuna treatment. The grain yields were 1.4-1.6 times higher in the long than the short rainy season. They were higher in experiment II than in experiment I.

Correlations between soil and plant chemical properties and plant growth variables were generally weak (data not shown). However, maize plant height at 35 DAP was significantly positively ($r = 0.73$, $P < 0.001$) correlated with N concentration in maize leaves. No relationship was found between N concentration in the stem and grain yield at harvest. By contrast, grain yield was significantly positively ($r = 0.93$, $P < 0.001$) correlated with plant height and significantly negatively correlated with both, the extent of stem tunnelling and the percentage of cobs damaged ($r = -0.76$ and $r = -0.51$, respectively, $P < 0.001$) (Table 5.6). The regression coefficient obtained from the covariance analysis showed that grain yield decreases by 0.761 ± 0.08 g for each unit increase in the extent of stem tunnelling.

Table 5.6. Correlation matrix of plant growth and plant damage variables at maturity of maize (computed across seasons and treatments).

	1	2	3	4
1 Grain weight/plant	-			
2 Plant height	0.93*	-		
3 Stem tunnelled	-0.76*	-0.89*	-	
4 Internodes bored	-0.01	0.01	-0.08	-
5 Ear damaged (%)	-0.51*	-0.35	-0.17	0.01

* r values with $P < 0.003$

Discussion

Busseola fusca densities and plant damage were higher in the first compared to the second growing season, corroborating results by Ndemah *et al.* (2001b). By contrast in West Africa, densities of *Sesamia* spp. and *E. saccharina*, the most important species in this region, reach economic important levels during the second season only (Schulthess *et al.*, 1997). According to Ndemah *et al.* (2003), the differences in seasonal importance of noctuid stemborers between the two regions were mainly due to a rapid increase in egg parasitism by *Telenomus* spp. (Hymenoptera: Scelionidae) from the first (long) to the second (short) growing season in Cameroon, with a concomitant decrease in pest density.

In the fallow and crop rotation systems, significantly higher stemborer densities were recorded than in the continuous maize cropping systems during the early part of plant growth. During this period, >98 % of the larvae collected were found feeding in the whorl. *Busseola fusca* lays its egg batches on the inner side of leaf sheaths of pre-tasseling plants (Kaufmann, 1983). Thereafter, they migrate to the whorl. After feeding on the whorl leaves, causing the typical 'window' symptoms, they then either disperse or bore into the stem from the top. It appears that the higher leaf N contents of plants in the fallow and crop sequence treatments lead to a higher arrestment or higher survival of young larvae. This corroborates results by Sétamou *et al.* (1993) from a fertilizer trial, which yielded a positive relationship between survival of young larvae and N applied. The trends in differences in pest infestations between treatments lasted until 49 DAP. Thereafter, as pest densities decreased sharply, differences ceased to be significant though differences in N levels were still apparent at 63 DAP. This suggests higher disappearance rates of larvae in the crop sequence with grain legumes and leguminous fallow than the continuous maize treatments. From the present experimental set-up it cannot be determined if this was due to shorter larval development time, increased plant-induced mortality or density dependent migration of older larval instars. However, Sétamou *et al.* (1993) showed for *S. calamistis* that nitrogen fertilizer levels did not affect egg-pupae development time on maize, suggesting that differences in disappearance were due to differences in mortality and/or migration.

It is well known that the N content of plants can be a crucial factor for the development and reproduction of herbivores (Strong *et al.*, 1984). Sétamou *et al.*

(1993) showed that N affects the survival of borer larvae (i.e., the young stages) before they penetrate into the stem. Our results showed that the short-term fallow with grain legumes (cowpea and soybean) and cover crops (mucuna and cajanus) contributed considerable amounts of N to succeeding maize crops, as N was significantly higher in both the soil and the plant in the fallow system compared to the maize-maize cropping system. This led to an increase in yields of 15.1-24.6 % after grain legumes and 30.3-42.5 % after cover crops fallow, in protected, and 17.0-38.0 and 34.0-54.7%, respectively, in unprotected maize, thus, yield differences were greater in the latter than the former. Hauser and Nolte (2002), who studied the response of maize to different *M. pruriens* varieties, found that N use efficiencies ranged between 0.19-0.74, with a 44-55 % increase in maize grain yields. On a degraded soil of the humid tropics but with higher rainfall, a short mucuna fallow yielded 75 % more maize grain than after natural regrowth (Hamadina *et al.*, 1996). In the present experiments, yield differences between bush and legume fallow were only 9.2-28.4% during the long, and 12.0-36.5% during the short rainy seasons. Horst and Härdter (1994), investigating the causal factors contributing to the differences in maize production between maize in rotation with cowpea and sequential cropping of maize, found that N nutrient in the flag leaves was the most important factor explaining yield differences between the two cropping systems. They observed a 17-34 % increase in maize grain yields without chemical fertilizer and a 31-42 % increase with 80 kg N ha⁻¹. There are many reports on the effect of N fertilization on stemborer infestations and yields and many of them stemmed from rice. For instance Saroja *et al.* (1987) reported that every increase in N levels resulted in an increase in incidence of both pests (e.g. *Scirpophaga incertulas* Walker (Lepidoptera: Pyralidae, Schoenobiinae)) as well as yield; according to Thakar and Mishra (1989), applying N to rice increased infestations by the stemborer *Tryporyza incertulas* Walker [*Scirpophaga incertulas*] and the leaf folder *Cnaphalocrocis medinalis* Guenée (Lepidoptera: Pyralidae, Pyraustinae) while in trials by Sharma and Reddy (1991) application of N to rice increased yields but also stemborer attacks. Similarly for maize, Martin *et al.* (1989) reported highest infestations by the European corn borer *Ostrinia nubilalis* (Hübner) (Lepidoptera: Pyralidae) at the highest level of N applied. For the pyralid *Diatraea grandiosella* Dyar, Archer *et al.* (1987) found that N increased pest infestations and stem damage while P decreased it, and combinations of N and P

were not different from the control. Atkinson and Nuss (1989), working on sugar cane, hypothesized that *E. saccharina*, a serious stem-boring pest of maize in West Africa (Schulthess *et al.*, 1997), did a host switch from wild sedges to sugar cane when stalk N of sugar cane reached sufficiently high levels for its survival as a result of intensive cultivation.

Conclusion

The present study is part of a project that investigates the use of habitat management techniques to reduce stem-borers incidence and damage in maize in the humid forest zone of Cameroon. In the present work, emphasis was given to the effects of soil fertility properties on grain yield and incidence of *B. fusca*, with special reference on the short-term effect of grain legumes and cover crops. Our results clearly show that sequences with leguminous crops appear to be the better management practice than a continuous maize production system, with more or less similar effects on borers as insecticide applications. Presently, we are investigating the direct effects of N and K on the bionomics of *B. fusca* and damage caused to maize in the field.

General Discussion

Maize is the most important cereal crop grown in Cameroon and cultivated in all agro-ecological zones. In the humid forest zone of southern Cameroon maize is the third most important food crop after groundnuts and cassava (Enyong, 1990; Almy *et al.*, 1990); farmers around the big cities of Yaoundé and Douala are market oriented and since the fall in cocoa prices, maize has become an important source of cash. The major constraints to maize production in the humid forest zone of southern Cameroon are low soil fertility and lepidopteran stem borers, which attack the crop at every growth stage. Ndemah *et al.* (1999) identified several factors that might be responsible for the temporal and spatial fluctuations of borer densities and which are investigated in the present study. Thus, the chapter 2 deals with the role of inland valleys, which are often planted with maize during the dry season; it was hypothesized that they are reservoirs for both stem borers and their natural enemies when upland maize is absent. Such information is relevant for the understanding of the population dynamics of the maize pests in the region and for predicting outbreaks.

As shown by Ndemah *et al.* (2003) from farmers' field surveys in the humid forest zone, borer infestations on maize were negatively related with density of associated crops and especially cassava. Thus, chapter 3 and 4 assessed the effects of different crop mixtures and planting arrangements on pest infestations and yield losses in maize.

The role of legumes in improving soil fertility properties and controlling weeds is widely documented (Vissoh *et al.*, 1998; Carsky *et al.*, 2001; Tian *et al.*, 2001). In addition Sétamou *et al.* (1995) showed that soil fertility, and especially nitrogen, increased both survival of immature *S. calamistis* and the plant ability to compensate for stemborer damage and as a result yield losses decreased with increased nitrogen fertilizer applied. Thus, chapter 5 elucidated the effect of maize-legume cropping sequences on both damage of maize by stem borers and maize yield.

Busseola fusca was the predominant borer species in all seasons and in both inland valley and in up-land maize fields. *Busseola fusca* populations were low in

the inland valleys maize fields, increased and reach high levels during the first cropping season, corroborating results by Cardwell *et al.* (1997) and Ndemah *et al.* (2001a). According to Ndemah *et al.* (2003), the differences in seasonal fluctuations of noctuid stem borers are mainly due to a strong increase in egg parasitism by *Telenomus* spp. from the first (long) to the second (short) growing season, with a concomitant decrease in pest density during the late season.

Most likely it was suggested that initial population size of stem borers at the beginning of the rains is important for the subsequent population build-up and mainly depends on the extent of rainfall and the native habitats adjacent to maize fields (Ndemah, 1999). *B. fusca* diapauses as larvae during periods of food scarcity (Usua, 1970). Thus, seasonal fluctuations are mainly the results of distribution of rainfall (Cardwell *et al.*, 1997; Ndemah *et al.*, 2000; Ndemah and Schulthess, 2002). Similarly results of the present study showed that the severity of attack in spring was influenced by the amount of rainfall (chapter 3). In addition, three sources of re-infestation, i.e., inland valley maize and grassy habitats as well as, old maize stubbles were identified and it could be concluded that especially inland valley maize plays a major role in the invasion of up-land maize by stem borers and natural enemies, during the first cropping season.

Furthermore, the proportions of non-diapausing *Sesamia* species were relatively high in the inland valleys indicating that they play a significant role in the perennation of natural enemies during the dry season.

In the intercrops, the temporal fluctuation of larval infestations more or less followed that of the monocrop, but pest densities were considerably lower, confirming results of older reports on cereal stem borer in Africa (Ampong-Nyarko *et al.*, 1995; Schulthess *et al.*, 2004). Van Rensburg *et al.* (1988) found that maize plant density had a significant effect on the extent of yield losses caused by *B. fusca* as its larvae tend to migrate to neighbouring plants; thus, the chances of the larvae to land on a host plant increased with plant density. Hence, in mixed cropping with non-host plants in the system, migration-related mortality of young larvae should be expected to be higher as a result of impaired host-finding. However, in the present study differences in egg-to-larva mortalities between cropping patterns were not significant, suggesting differences in larval densities between mono and mixed cropping were due to differences in oviposition rates, corroborating results by Schulthess *et al.* (2004) for *S. calamistis* in a cassava-

maize relay-cropping system. In addition, the overall rating of the mixed cropping systems, expressed by their land-equivalent-ratio (LER) and area-time-equivalent-ratio (ATER), indicate that the crop mixtures used in this study effectively balanced competition between the plant species, consequently leading to a greater land use efficiency in inter- compared to monocrops. Particularly in terms of monetary values, it was shown to be desirable to plant maize with non-host plants rather than using insecticides like furadan in a maize monocrop, underlying the self-sustaining role of maize intercropping with cassava or legume food crops for small-scale farmers with limited resources, in marginal agricultural areas like the humid forest zone of Cameroon.

As suggested by Saroja *et al.* (1987) and Martin *et al.* (1989), improving soil fertility can effectively complement pest control. Based on the findings of the present study, the integration of grain legumes or cover crops as short fallow improved the supply of mineral N in the soil and the nutritional status of maize, which enhanced its tolerance to pests. For the farmers in the study area, changing their predominant monocrop maize system to a rotation with legumes appears to be the better management practice than applying insecticides for combating stem borers. Both technologies showed similar effects on *B. fusca*, but grain legumes generate extra cash income or food for farmers and cover crops, thus, ameliorate the overall sustainability of the system.

Results of the present study clearly indicate that managing the diverse pest complexes of maize in the humid forest zone of Cameroon will require multiple and integrated control practices tailored to the needs of farmers with varying production goals. Intercrops will certainly constitute a key component in any strategy to control maize stem borers in this region. As indicated by the importance of legumes as short fallow in reducing yield losses due to borers in the subsequent crop, direct application of N could form a strong component of an IPM package against *B. fusca*. This was demonstrated by Sétamou *et al.* (1995) for *S. calamistis* in the derived savanna of Benin. Further research need to investigate the direct effects of N and K on the bionomics of *B. fusca* and damage caused to maize in the field.

The present work will be complemented by a project on IPM of cereal stem borer in western Africa. The proposal was developed by the International Centre of Insect Physiology and Ecology (ICIPE) and will be funded by BMZ. Major

emphasis will be on the new association biological control approach. Major emphasis will be given to the new association biological control (Weidenmann and Smith, 1997) and redistribution approach (Schulthess *et al.*, 1997). Because of their stabilizing effects on the pest-parasitoid system in an area, inland valleys should be targeted for releases of natural enemies.

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Acknowledgements

This project proposal was funded by the German Research Council. Field studies were carried out in Cameroon from October 2001 to December 2004.

I am most indebted to my supervisors Prof. Dr. Borgemeister, Drs. F. Schulthess and C. Nolte who followed my progress through valuable discussions, comments and suggestions.

I'm grateful for Dr. R. Ndemah who offered the opportunity to rear insects in her laboratory. Identification of larval parasitoids was provided by Dr. G. Goergen, from the Insect Museum of IITA in Cotonou, Benin. I wish to thank also all my technicians, administration staff and associated scientists of IITA Cameroon and Cotonou for providing technical assistance.

My sincere gratitude goes for my parent and particularly my wife Aina, Marcelle and my boy Chabi-Olaye M.L. Faik who endured the periods of my absence from home in Benin, with remarkable fortitude.

I am solely responsible for the views expressed in this report and hope that the assembled information provides a useful tool for scientists working on the management of cereal stem borers in Africa.

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