ROLE OF HABITAT MANAGEMENT TECHNOLOGIES IN THE CONTROL OF CEREAL STEM AND COB BORERS IN SUB-SAHARAN AFRICA

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ABSTRACT
Floral and faunal biodiversity is relevant to pest management in many ways. In the present paper emphasis is given to the use of alternative wild and cultivated host plants as trap plants, mixed cropping and management of soil nutrients through mineral nutrition and use of leguminous cover crops in crop rotation systems for integrated control of maize cob and stem
borers in sub-Saharan Africa. Our findings indicate that hydromorphic inland valleys (IVs) are reservoirs for borers and their natural enemies in upland maize fields. Populations of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), the most important borer in Cameroon, were low in IV maize fields, increased and reached high levels during the first and second cropping season in adjacent upland maize fields, while egg parasitism of borers was 40 % higher in the dry compared to the first rainy seasons, in IV and upland maize fields, respectively. Thus, IVs should be targeted for inundative releases in biological control programs. Wild host plants, namely grasses, are highly attractive to ovipositing female moths. However, results from laboratory studies on the survival of immature stages of stem borer on different grass species showed that no *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) and *Eldana saccharina* (Walker) (Lepidoptera: Pyralidae) larvae pupated on *Pennisetum polystachion* (L.) Schult, indicating the role of wild hosts as trap plants in the vicinity of maize fields. Depending on the wild host plant and borer species, larval densities were reduced by 30-60 % in maize fields surrounded by wild grasses. Consequently up to twofold higher levels of plant damage were recorded in maize without compared to maize with surrounding grasses. Depending on the crop association and planting pattern, intercropping maize with non-host plants reduced egg and larval densities of borers by 52.6-73.7 % and 34.3-51.5 %, respectively, compared to a maize monocrop. Consequently maize yield losses due to stem borers were up to twofold lower in inter- than in monocrops. All intercropping systems had the additional advantage of higher land productivity than the maize monocrop. A maize-cassava intercrop was most efficient in terms of land use, and thus recommendable for land-constrained poor farmers. Average densities of *B. fusca* at 42 days after planting were generally higher after maize-maize and additional nitrogen (N) fertilization of 60 or 120 kg/ha than after a short fallow of leguminous food or cover crops, and higher after legumes than after maize-maize without additional N doses. However, egg-larval mortalities were up to two-fold lower in maize-maize compared to legume-maize treatments. As a result, extent of dead-hearts did not vary significantly among treatments. The average yield losses due to borers were five times higher in the maize-maize sequence without additional N compared to both a legume-maize sequence and maize-maize and additional N dose treatments, suggesting that an increased nutritional status of the plant enhanced both borer fitness and plant vigor, but with a net-benefit for the plants.

**INTRODUCTION**

Maize, *Zea mays* L., is an important component of the farming systems in sub-Saharan Africa (SSA), where it is a staple for a large proportion of the population. Food security and human nutritional status of small-scale and resource-poor farmers are directly impacted by losses in quantity and quality of the harvested crop. In some cases, losses due to pests and diseases, both pre- and post-harvest, far outweigh any reasonable hope for increases in productivity through improved germplasm and pre-harvest management. The most damaging field pests of maize in SSA are lepidopterous stem and cob borers belonging to the families Noctuidae, Pyralidae and Crambidae (see overview by Polaszek 1998). Stem and cob borers such as *Sesamia calamistis* Hampson, *Busseola fusca* (Fuller) (both Lepidoptera: Noctuidae), *Eldana saccharina*...
Mussidia nigrivenella Ragonot (both Lepidoptera: Pyralidae) are indigenous to Africa and have moved on to maize after having evolved on native grasses or cereals such as sorghum and millet, and other host plant species. In contrast, Chilo partellus (Swinhoe) (Lepidoptera: Pyralidae) has been accidentally introduced from Asia (Nye 1960). In recent years, maize is increasingly replacing indigenous cereal crops, such as sorghum and millet, as well as wild habitats in SSA; consequently, it has become the major host of insect pests.

Yield losses in areas with severe borer problems vary between 10-70% (Bosque-Pérez and Mareck 1991; Cardwell et al. 1997; Sétamou et al. 2000). In addition, grain damage by lepidopterous borers predisposes maize to pre- and post-harvest infestations by storage beetles, infections by Aspergillus flavus Link and Fusarium verticillioides (Saccardo) Nirenberg, and subsequent contamination with mycotoxins (Cardwell et al. 1997; Sétamou et al. 2000). Results from diagnostic surveys indicate that the pest situation in SSA is complex, and that the relative importance of a borer species varies between regions (western vs. eastern Africa), ecosystems within a country, or even within the same eco-region of neighboring countries. In West Africa, the most frequently reported maize pests are *S. calamistis*, *E. saccharina* (Bosque-Pérez and Mareck 1990; Gounou et al. 1994; Schulthess et al. 1997), and the noctuid *S. botanephaga* (Tams and Bowden) (Endrody-Younga 1968). *B. fusca* is generally of low importance in West Africa but the predominant species across all eco-zones in Cameroon (Cardwell et al. 1997; Chabi-Olaye et al. 2005a,b; Ndemah 1999; Schulthess et al. 1997). The crambid *Coniesta ignefusalis* Hampson, a pest of millet in the Sahelian and savanna regions (Nwanze 1991), is occasionally found on maize in all eco-zones. Other species found in the system are *S. poephaga* Tams and Bowden, mainly a minor pest of sorghum in the Guinea and Sudan savannas (Schulthess et al. 1997), and *Chilo* spp. (Moyal and Tran 1991). In East and southern Africa, the most damaging cereal borers are *C. partellus*, particularly in warmer lowland areas (Nye 1960), and *B. fusca* (Overholt et al. 1994).

Habitat management strategies, in which available natural resources such as wild hosts and non-host plants of stem borers are used against indigenous stem borer species, can increase the understanding of interactions between pests, their cultivated and wild hosts, as well as their natural enemy fauna on both types of host plants (Khan et al. 2000; Ndemah et al. 2002; van den Berg et al. 2001). In general, wild hosts are believed to be a reservoir for stem borers and responsible for pest outbreaks on crops (Bowden 1976; Sampson and Kumar 1986). However, other authors have argued that grasses harbor natural enemies that prevent stem borers from reaching damaging levels on crops or act as trap plants (Schulthess et al. 1997).

Recent studies by Chabi-Olaye (unpublished data) indicated that hydromorphic inland valleys (IVs), in which maize is grown during the dry season, maintain carry-over populations of not only *B. fusca* but also of its natural enemies in the humid forest of Cameroon. These findings show that a more complete understanding of the role of wild hosts and IVs in insect pest outbreaks will be useful in generating suitable management strategies for lepidopterous cob and stem borers.

In many regions of SSA maize is traditionally intercropped with various other crops. Generally, intercropping allows more efficient land use, and ensures the availability of food throughout the seasons (Mutsaers et al. 1993; Vandermeer 1989). The importance of plant biodiversity in agro-ecosystems for reducing crop losses by pests has long been recognized (Baliddawa 1985; Litsinger and Moody 1976; Okigbo and Greenland 1976). 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 cropping systems (Altieri and Letourneau 1982; Cromartie 1981; Kareiva 1983; Risch et al. 1983). Such a habitat management strategy has also been tested against stem borers in SSA. A considerable reduction in stem borer densities was found when maize was intercropped with non-hosts such as cassava or legumes (overview by van den Berg et al. 1998). Mixed cropping systems also have additional advantages such as a higher land productivity and are thus recommendable for land-constrained poor farmers who do not use external inputs such as fertilizer.

It is known that favorable nutrition often improves the ability of plants to withstand pest attack (Chabi-Olaye et al. 2005a; Denké 1995; Sétamou et al. 1993; 1995). Moreover, surveys by Ndemah (1999) showed a negative relationship between B. fusca densities and potassium (K) content of soil, suggesting that improvements of soil fertility can complement pest control measures in Africa.

The present paper reports on the development of habitat management technologies against cob and stem borers in SSA, and discusses the implications for their adoption by small-scale farmers in SSA.

MATERIALS AND METHODS

ROLE OF CULTIVATED INLAND VALLEYS

During the dry season in the humid forest zone of Cameroon, maize is the most important cash crop grown in hydromorphic inland valleys (IVs). Such dry season fields, however, may also be reservoirs for pests such as B. fusca and its natural enemies, which invade adjacent upland maize fields during the rainy seasons. From 2002 through 2004 we monitored pest and parasitoids in IVs and nearby upland maize fields. Surveys in each year started during the dry season in the IVs and were extended to upland maize fields during the first and second cropping seasons. Depending on the availability of maize, 10-12 IV maize fields were investigated per dry season. During the first and second cropping season, 1-2 up-land maize fields were sampled around each cultivated IV. Fields were visited two times, i.e., at the vegetative stage and at harvest. At each visit, 24 maize plants were sampled destructively. Data on the number of borer eggs, parasitized eggs, larval densities and their parasitism were gathered.

WILD HOST SURVEY

The wild grasses Sorghum arundinaceum (Desv.) Stapf, Panicum maximum Jacq., Andropogon gayanus Kunth, Pennisetum polystachion (L.) Schult and P. purpureum Moench are known to be the most common alternative host plants of stem borers in SSA (Khan et al. 1997; 2000; Gounou and Schulthess 2004; Schulthess et al. 1997; van den Berg et al. 1997), and their abundance is strongly negatively related to borer incidence in maize fields (Cardwell et al. 1997; Schulthess et al. 1997). Differences in the relative abundance of borers and the survival of their progeny in the different wild host species may provide some clues for the management of stem borers. The data presented here are based on results of surveys carried out in Benin, Ghana, and Cote d’Ivoire (Gounou et al. 2004; Schulthess et al. 1997). Sampling was carried out through the first and second growing season along roadside fields at 10-25 km intervals.
Additional samples were also taken in IVs. At each sampling site 100–200 grass tillers were randomly sampled. The number of infested tillers was counted, and plants were dissected and borers collected, and counted according to species level. In addition, *S. calamistis* and *E. saccharina* were reared on pieces of stems from the before mentioned five grass species and larval survival was recorded (Shanower *et al.* 1993).

**USE OF ALTERNATIVE WILD AND CULTIVATED HOST PLANTS AS POTENTIAL TRAP PLANTS**

Wild hosts, i.e., *S. arundinaceum*, *P. maximum*, and *P. polystachion* in Benin and *P. purpureum* in Cameroon, were evaluated as trap plants for stem borers in field experiments. Experiments were carried out during the first and second growing season of 1997 in the humid forest zone of Cameroon, and in the second growing season of 1999 in the derived savanna zone of Benin. 100-144 m² maize plots were surrounded by 1 m border rows of grasses. Grass tufts were planted during the first season of 1997 in Cameroon, and the second season of 1998 in Benin. A control treatment of non-surrounded maize was planted away from the maize-grass treatments to reduce interactions between treatments. Each treatment was replicated four times. Maize was planted at 53,333 plants/ha. Two to three weeks after planting maize plants received NPK fertilizer (15:15:15) at a rate of 160-250 kg in Benin and Cameroon, respectively. Fields were kept weed free. 21 days after planting (DAP), 24 maize plants were randomly sampled at two-weekly intervals for assessment of plant damage (% stems bored and % dead-hearts), borer abundance and their natural enemies. Five to eight samplings were taken in Benin and Cameroon, respectively.

*M. nigrivenella* has been frequently reported as a pest of maize (Bosque-Pérez and Mareck 1990; Gounou *et al.* 1994; Moyal 1988; Moyal and Tran 1991) and cotton, *Gossypium hirsutum* L. (Silvie 1990; Staeubli 1977). High infestations of *M. nigrivenella* were also reported from velvetbean *Mucuna pruriens* DC. and jackbean *Canavalia eneiformis* (L.) DC. (Schulthess and Gounou unpublished data). The two leguminous cover plants are green manure crops, introduced to Africa in the last decades for improving soil fertility and controlling weeds (Carsky *et al.* 1998; Vissoh *et al.* 1998;) and are increasingly used by farmers in SSA. A detailed study on the infestation and preference of *M. nigrivenella* on maize, cotton, jack- and velvetbeans was carried out by Sétamou (1999). The experimental design consisted of a randomized block with three replications containing four plots of 25 m x 25 m each. The distance between blocks was 4 m, and that between plots within a block 2 m. Each host plant was planted in early May 1995 at a density of 31,250 and 25,000 plant stands/ha for maize and cotton, respectively, and 16,500 plants/ha for both jack- and velvetbeans. Maize and cotton crops received NPK (15-15-15) fertilizer at a rate of 200 kg/ha, two weeks after sowing. For each crop, sampling started as soon as 50 % of the fruits were formed. The borer populations were monitored at weekly intervals until harvest. The percentage of fruits infested with all stages of *M. nigrivenella* in the sample was calculated for each host plant on each sampling date.

**INTERCROPPING**

In these experiments, conducted in the humid forest zone of Cameroon, four crop species were used, i.e., a 110-day open pollinated variety of maize (Cameroon Maize Series [CMS]
8704), a late maturing soybean *Glycine max* (L.) Merr. (var. TGX 1838-5E), an erect type of cowpea *Vigna unguiculata* (L.) Walp. (var. Asonten) and a local variety of cassava *Manihot esculenta* Crantz (called ‘automatic’ by farmers). Maize was grown as a monocrop or intercropped with cassava, cowpea or soybean. In the intercropping treatments, maize was planted 12-14 days after the non-host plants. Two spatial arrangements were used in the intercrops, i.e., (i) a within row arrangement where each maize plant was followed by a non-host plant, and (ii) strip planting in which two rows of maize were followed by two rows of a non-maize crop, with one row of non-host plants as first and last row borders. Each experiment had a control plot with an insecticide treatment to allow an estimation of yield losses due to borer attack. 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. The treatments were arranged in a completely randomized block design with four replications. Plots were 6 × 12 m each. The planting patterns were chosen such that maize populations in all intercrops were the same (26,667 plants/ha) except in the case of alternate hill planting with cassava where the plant population was reduced to 20,000 plants/ha. In the monocrops plant densities were chosen to be ‘optimal’ for the region, i.e., those that produce the highest yield.

During the vegetative stage, 80 and 40 maize plants/plot were checked weekly in the mono- and intercrops, respectively, for stem borer egg batches. Larval densities were evaluated on 24 and 12 randomly sampled plants per plot in mono- and intercrops, respectively. Sampling started 28-35 DAP and was continued at biweekly intervals until maturity of maize cobs. At each sampling date, maize plants were dissected and borer larvae and pupae were identified to species and counted on a per plant/plot level. Borer tunnel length and maize yields were estimated on four pre-determined sub-plots of 1.5 m × 2 m per treatment at harvest.

**IMPROVED PLANT NUTRITION THROUGH MINERAL FERTILIZER AND LEGUMINOUS COVER CROPS**

In 2003, field trials were set up in the humid forest zone of Cameroon to assess the effect of maize-legume cropping sequences and continuous maize growing with and without mineral fertilizer on both stem borer infestations, with a special emphasis on *B. fusca*, and maize yield losses. In the long-short rainy seasons sequence (herewith referred to experiment 1), cover crops were planted mid 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 on September 5 of the same year. In the short-long rainy seasons sequence (herewith referred to experiment 2), which lasts from September to August in the next year, cover crops were planted on September 15 and the succeeding maize on March 25. The maize-maize cropping system had three levels of mineral fertilizer, i.e., 0, 60 and 120 kg N/ha. Each experiment had a control plot with an insecticide treatment to allow an estimation of yield losses due to borer attack. The treatments were arranged in a completely randomized block design with four replications. Plots were 6 × 6 m each. 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. N was applied in form of urea. The two different N-levels (60 and 120 kg/ha) were equally split in two and three dosages, respectively, and were applied 14, 28 and 56 DAP. 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 were thinned to two plants per hill 14 DAP. Plots were manually kept weed free. 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. Twelve plants per plot were sampled destructively every two weeks starting from 21 DAP until harvest. The number of borer eggs and larvae per plant and percentage of plants with dead-heart symptoms were recorded in insecticide-free plots. For each treatment, borer tunnel length and maize yield were estimated on four pre-determined sub-plots of 1.5 m x 2 m at harvest.

**STATISTICAL ANALYSES**

Differences in plant infestation, pest abundance and damage variables, i.e., % stems bored, dead-hearts and yield losses were analyzed by analysis of variance (ANOVA), using the general linear model (GLM) procedure of SAS (SAS 1997). The t-test with Bonferroni probability adjustment was used to compare the different wild host plants and seasons. The variation in pest abundance in the mixed cropping systems over sampling days was analyzed by ANOVA, using the mixed model procedure of SAS with repeated measures (SAS 1997). Least squares means (LSM) were separated using the t-test. The significance level was set at $P = 0.05$. The effect of host plants on *M. nigrivenella* infestation levels was evaluated using the closed testing procedures (Hochberg and Tamhane 1987). The percentage of fruits infested for each host plant species were ranked within sampling date. The Chi-square test was then applied on the total sum of ranks of each host plant, to evaluate independence of *M. nigrivenella* infestations according to host plants using the PROC FREQ procedure of SAS (SAS 1997). Maize yield losses due to cob and stem borers were assessed on an area basis as follows:

$$100 \times \frac{(Y_i - Y_t)}{Y_i}$$

where $Y_i$ and $Y_t$ are the mean yields of insecticide-treated and non-treated plots, respectively.

The overall efficiency of intercropping systems was assessed using the land-equivalent-ratio (LER). It is calculated after Mead and Willey (1980) as follows:

$$LER = \frac{I_a}{M_a} + \frac{I_b}{M_b}$$

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 monocrops. 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.

**RESULTS**

**ROLE OF INLAND VALLEYS**

The percentage of plants infested and larval densities varied significantly between IV and upland maize fields (Table 1). Percentage plants infested and borers densities did not differ between the first and second growing seasons, and the averages were 3.3 and 5.0 times, respectively, lower than in the dry season/IV (Table 1). *B. fusca* was the most abundant borer
species across seasons and no differences were found in its abundance among seasons (Table 1). However, *Sesamia* sp. and *M. nigrivenella* densities were 14.6 and 3.1 times, respectively, higher in the dry season/IV than in the first and second growing seasons (Table 1). Few borer larvae and pupae were parasitized. However, levels of egg parasitism were similarly high during the dry/IV and the second growing seasons, and the average being 1.7 times higher than during the first growing season.

**Table 1.** Infestation, abundance and parasitism of stem borers in inland valley and up-land maize fields in the humid forest zone of Cameroon.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cropping seasons¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
</tr>
<tr>
<td>Infested plants (%)</td>
<td>15.0 ± 2.2b</td>
</tr>
<tr>
<td>No. of larvae/plant</td>
<td>0.55 ± 0.04b</td>
</tr>
<tr>
<td>Species abundance (%)</td>
<td></td>
</tr>
<tr>
<td><em>B. fusca</em></td>
<td>70.5 ± 4.2a</td>
</tr>
<tr>
<td><em>Sesamia</em> sp.*</td>
<td>18.2 ± 5.5a</td>
</tr>
<tr>
<td><em>E. saccharina</em></td>
<td>8.3 ± 1.2a</td>
</tr>
<tr>
<td><em>M. nigrivenella</em></td>
<td>2.9 ± 0.4a</td>
</tr>
<tr>
<td>Parasitism (%)</td>
<td></td>
</tr>
<tr>
<td>Egg</td>
<td>43.2 ± 6.0a</td>
</tr>
<tr>
<td>Larvae + pupae</td>
<td>3.5 ± 1.8a</td>
</tr>
</tbody>
</table>

¹The first and second growing seasons last typically from mid March to mid July and from mid August to end of November, respectively. The major dry season starts in the third week of November and lasts through end of February or beginning of March of the following year. Within row means followed by the same letters are not significantly different at P = 0.05 (Bonferroni t-test).

**ROLE OF WILD AND CULTIVATED LEGUMINOUS HOST PLANTS**

Borer densities did not significantly differ among the most often reported wild hosts (Table 2). However, the percentage of infested tillers was significantly higher in *S. arundinaceum* compared to the other plants (Table 2). *S. calamistis* was most abundant on *P. maximun* and *P. polystachion* and less on *P. purpureum* (Table 2). By contrast, *B. fusca* was more frequently found on *P. purpureum* than on *S. arundinaceum* and no *B. fusca* larvae were collected on other plants. However, percentage of larvae-pupal survival was < 7 % on all five wild hosts and on *P. polystachion* no *S. calamistis* and *E. saccharina* and on *P. maximum* no *E. saccharina* larvae pupated (Table 2).

Both in the derived savanna of Benin and humid forest of Cameroon, borer densities were significantly reduced in maize surrounded by wild gramineous hosts compared to non-surrounded maize (Table 3). *S. calamistis* and *E. saccharina* densities were reduced by 51.2 % and 34.1 %, respectively, in maize surrounded by wild hosts compared to the non-surrounded one in the derived savanna of Benin. However, *E. saccharina* densities did not differ among surrounded and non-surrounded maize in both the derived savanna of Benin and the humid forest zone of Cameroon. However, in Cameroon, *B. fusca* density was 1.7 times lower in
maize surrounded by *P. purpureum* compared to non-surrounded maize (Table 3). Consequently, depending on the grasses the percentage of stems bored was 1.2-2 times in Benin and 2.2 times in Cameroon lower in maize plots surrounded by grasses than in the non-surrounded maize (Table 3). In the derived savanna of Benin the percentage of egg parasitism was 2.0-2.3 times higher in surrounded compared to non-surrounded maize (Table 3).

**Table 3.** Least square means of stem borer numbers and plants damaged in maize surrounded and not surrounded by different grass species in Benin: *Pennisetum polystachion* (Ps), *Sorghum arundinaceum* (Sa) and *Panicum maximum* (Pm); and in Cameroon: *P. purpureum* (Pp).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Wild host species</th>
<th>Derived Savanna, Benin</th>
<th>Humid Forest, Cameroon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Andropogon gayanus</em></td>
<td><em>Panicum maximum</em></td>
<td><em>Pennisetum purpureum</em></td>
</tr>
<tr>
<td>Infested tillers (%)</td>
<td>4.9 ± 0.7b</td>
<td>11.0 ± 3.6b</td>
<td>7.1 ± 2.0b</td>
</tr>
<tr>
<td>No. of borers/plant</td>
<td>0.23 ± 0.2a</td>
<td>0.46 ± 0.3a</td>
<td>0.91 ± 0.7a</td>
</tr>
<tr>
<td>Abundance (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. calamistis</em></td>
<td>66.1 ± 2.7b</td>
<td>90.8 ± 2.1a</td>
<td>12.5 ± 5.8c</td>
</tr>
<tr>
<td><em>E. saccharina</em></td>
<td>33.9 ± 2.7a</td>
<td>9.2 ± 2.1b</td>
<td>10.7 ± 4.4b</td>
</tr>
<tr>
<td><em>B. fusca</em></td>
<td>0b</td>
<td>0b</td>
<td>76.9 ± 7.5a</td>
</tr>
<tr>
<td>Survival (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. calamistis</em></td>
<td>0.3</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td><em>E. saccharina</em></td>
<td>0.3</td>
<td>0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

1Relative abundance of borer species calculated as percentage of density of the species over total borers collected; 
2Data from Shanower et al. (1993). Within rows, means followed by the same letters are not significantly different at P = 0.05 (Bonferroni t-test).
There were significant differences between the sums of fruit infestation ranks (Table 4) of the different host plants ($\chi^2 = 65.33$, df = 6, $P < 0.001$). Infestation of *M. pruriens* pods was significantly higher than that of maize and cotton ($\chi^2 = 13.0$, df = 4, $P < 0.05$), but there were no significant differences among the sums of the infestation ranks of maize and cotton when tested alone ($\chi^2 = 5.6$, df = 3, $P > 0.05$). *C. enseiformis* had significantly higher number of pods infested compared to *M. pruriens* ($\chi^2 = 24.0$, df = 3, $P < 0.001$). Hence, the closed testing procedure revealed that *M. nigrivenella* infestation was significantly highest on *C. enseiformis*, with highest levels at all sampling occasions (Table 4).

**Table 4.** Sum of weekly ranks of *Mussidia nigrivenella* infestation levels observed on four crops in Benin.

<table>
<thead>
<tr>
<th>Cultivated Crops</th>
<th>Sum of Infestation Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><em>Zea mays</em> L</td>
<td>0</td>
</tr>
<tr>
<td><em>Gossypium hirsutum</em> L.</td>
<td>0</td>
</tr>
<tr>
<td><em>Mucuna pruriens</em> DC</td>
<td>0</td>
</tr>
<tr>
<td><em>Canavalia enseiformis</em> (L.) DC.</td>
<td>12</td>
</tr>
</tbody>
</table>

$^1$Data from Sétamou (1999).

**INTERCROPPING**

Results of the analysis of variances showed that egg batch and larval densities of *B. fusca* were not affected by the crops associated with maize in the intercropping treatments (Table 5). However, the egg batch density differed significantly between strip and within row planting (Table 5). Thus, the egg batch and larval densities, as well as the damage variables were presented per spatial arrangement.

Intercrops of maize with non-host plants significantly reduced the oviposition, infestation and damage due to borers compared to maize monocrop (Table 6). Yet, overall the within row planting reduced the borer egg batches per plant by 73.7 % and larval abundance by 51.5 % compared to sole maize, but treatments did not differ in terms of egg-larval mortality (Table 6). The percentages of stems bored and yield losses did not differ between the two spatial arrangements of the intercrops, and were 5.2 and 2.0 times lower than in the maize monocrop for strip and within row planting, respectively (Table 6).

**Table 5.** Results of ANOVA on the differences in borer densities between treatments (data pooled across sampling days and seasons).

<table>
<thead>
<tr>
<th>Source of variance$^1$</th>
<th>Egg batch/plant</th>
<th>Busseola fusca/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d.f.</td>
<td>F</td>
</tr>
<tr>
<td>Spatial arrangement (SA)</td>
<td>1; 177</td>
<td>23.57</td>
</tr>
<tr>
<td>Crop (C)</td>
<td>2; 177</td>
<td>1.38</td>
</tr>
<tr>
<td>SA*C</td>
<td>2; 177</td>
<td>1.59</td>
</tr>
</tbody>
</table>

$^1$Two spatial arrangement, i.e., strip and within row planting. The non-host plants cropped with maize are cassava, cowpea and soybean.
The overall efficiency of intercrops is presented in Figure 1. The greater land-equivalent-ratios were obtained when maize was associated with cassava (LER ranged between 1.6 and 1.8). The lowest LER was recorded in maize-legumes with values ranging between 1.15 and 1.45 (Fig. 1).

**Table 6.** Effect of intercropping on the oviposition, infestation and damage (least square means ± SE) due to *Busseola fusca* in the humid forest of Cameroon.

<table>
<thead>
<tr>
<th>Spatial Arrangement</th>
<th>Oviposition and infestation</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Egg Batch per Plant</td>
<td>B. fusca per Plant</td>
</tr>
<tr>
<td>Maize monocrop</td>
<td>0.38 ± 0.04a</td>
<td>1.34 ± 0.22a</td>
</tr>
<tr>
<td>Maize + non-host plant strip-planted</td>
<td>0.18 ± 0.02b</td>
<td>0.88 ± 0.13b</td>
</tr>
<tr>
<td>Maize + non-host plant within-row planted</td>
<td>0.10 ± 0.02c</td>
<td>0.65 ± 0.12b</td>
</tr>
</tbody>
</table>

\(^1\)Egg to larva mortality; within columns, means followed by the same letter are not significantly different at P = 0.05 (t-test).

**Figure 1.** Relationship between land equivalent ratio and crops (maize and associated crops in the intercrops) yields.
PLANT NUTRITION

For both experiments, differences in *B. fusca* larval densities were significant at 42 DAP, while no differences were found among treatments at 63 DAP (Table 7). Average densities of *B. fusca* at 42 DAP and egg-larval mortalities were generally higher following maize-maize with 60 or 120 kg N/ha than following legumes, and higher after both leguminous plants than after maize-maize without additional N (Table 7). Data on stem tunneling and yield losses differed significantly among treatments while no such differences were found in both experiments in the percentages of dead-hearts (Table 7).

In both experiments the greatest extent of stem tunneling was found in the maize-maize and 120 kg N/ha treatment, and no difference was found between the maize after legumes and the maize-maize without additional N treatments (Table 7). By contrast, in both experiments the highest yield losses were found in the maize-maize without additional N treatment. Overall, *B. fusca* densities at 42 DAP and the extent of stems tunnelled were 1.1-1.4 and 1-1.8 times, respectively, higher in experiment 1, where maize was planted during the long-short rainy seasons sequence, than in experiment 2, where maize was planted during the short-long rainy seasons sequence.

Table 7. Effect of different fallow and rotation systems on least square means (± SE) of *Busseola fusca*, egg to larvae mortality and damage variables in the humid forest of Cameroon.

<table>
<thead>
<tr>
<th>Treatments1</th>
<th><em>B. fusca</em> per plant</th>
<th>Egg-larva mortality (%)</th>
<th>Stem tunneling (cm)</th>
<th>Dead-hearts (%)</th>
<th>Yield loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>42 DAP</td>
<td>63 DAP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize-maize</td>
<td>1.67 ± 0.3c</td>
<td>1.22 ± 0.1a</td>
<td>45.9 ± 2.5c</td>
<td>22.0 ± 4.8b</td>
<td>3.8 ± 0.3a</td>
</tr>
<tr>
<td>Maize-maize + 60 kg ha-1</td>
<td>4.25 ± 0.5a</td>
<td>1.11 ± 0.2a</td>
<td>88.2 ± 4.8a</td>
<td>24.7 ± 4.9b</td>
<td>4.1 ± 0.3a</td>
</tr>
<tr>
<td>Maize-maize + 120 kg ha-1</td>
<td>4.58 ± 0.3a</td>
<td>1.19 ± 0.1a</td>
<td>91.5 ± 5.1a</td>
<td>59.8 ± 4.7a</td>
<td>4.0 ± 0.3a</td>
</tr>
<tr>
<td>Maize-soybean</td>
<td>2.62 ± 0.3b</td>
<td>1.10 ± 0.1a</td>
<td>70.3 ± 3.2b</td>
<td>14.8 ± 4.1b</td>
<td>3.7 ± 0.2a</td>
</tr>
<tr>
<td>Maize-mucuna</td>
<td>3.33 ± 0.2b</td>
<td>1.10 ± 0.1a</td>
<td>69.2 ± 3.8b</td>
<td>16.9 ± 4.2b</td>
<td>4.1 ± 0.2a</td>
</tr>
<tr>
<td>Maize-maize</td>
<td>1.39 ± 0.2d</td>
<td>1.03 ± 0.2a</td>
<td>38.4 ± 3.1c</td>
<td>19.5 ± 1.9b</td>
<td>2.8 ± 0.3a</td>
</tr>
<tr>
<td>Maize-maize + 60 kg ha-1</td>
<td>3.03 ± 0.1ab</td>
<td>1.33 ± 0.2a</td>
<td>85.8 ± 3.5a</td>
<td>20.4 ± 2.0b</td>
<td>2.9 ± 0.4a</td>
</tr>
<tr>
<td>Maize-maize + 120 kg ha-1</td>
<td>3.22 ± 0.2a</td>
<td>1.41 ± 0.1a</td>
<td>88.2 ± 4.2a</td>
<td>32.0 ± 1.8a</td>
<td>3.0 ± 0.3a</td>
</tr>
<tr>
<td>Maize-soybean</td>
<td>2.46 ± 0.1bc</td>
<td>1.21 ± 0.1a</td>
<td>63.3 ± 3.4b</td>
<td>15.7 ± 1.6b</td>
<td>3.2 ± 0.2a</td>
</tr>
<tr>
<td>Maize-mucuna</td>
<td>2.67 ± 0.2c</td>
<td>1.19 ± 0.1a</td>
<td>58.5 ± 2.8b</td>
<td>16.2 ± 1.8b</td>
<td>3.6 ± 0.2a</td>
</tr>
</tbody>
</table>

1Experiment 1 was conducted during the long and short rainy seasons sequence and Experiment 2 during the short and long rainy seasons sequence. Within columns, means followed by the same letter are not significantly different at P = 0.05 (t-test).
RESULTS

Results of the countrywide surveys on stem and cob borers in West Africa so far showed that borers oviposited heavily on wild host plants but their relative importance, both on maize and wild grasses, varied between regions, eco-zones and within the same eco-zone (Schulthess et al. 1997). *S. calamistis* and *E. saccharina*, the most frequently reported maize borers in West Africa (Bosque-Pérez and Mareck 1990; Gounou et al. 1994; Schulthess et al. 1997), were found in several grasses, but *S. calamistis* was seven times more abundant on *P. maximun* and *P. polystachion* than on *P. purpureum*, while *E. saccharina* was equally abundant on the three surveyed grasses. However, depending on the grass species *S. calamistis* abundance was 1.5-10 times higher than that of *E. saccharina*. *B. fusca*, the predominant borer in the humid forest of Cameroon (Chabi-Olaye et al. 2005b; Ndemah 1999; Schulthess et al. 1997), where wild grasses are scarce (Ndemah et al. 1999), was 10.3 times higher on *P. purpureum* than on *S. arundinaceum*. Given the geographic distribution of stem borers and the role of wild host plants, Schulthess et al. (1997) argued that the differences in relative importance of species may be due to differences in human population densities. Increasing population pressure and the concomitant expansion of agricultural areas often result in deforestation and displacement of wild habitats of borers, which probably affect the population dynamics of both borers and their natural enemies.

In the humid forest of Cameroon, lower densities of *B. fusca* were found in the IVs compared to up-land maize fields during the first and second cropping seasons. However, its abundance compared to other borer species in the area did not vary considerably among seasons. By contrast, *S. calamistis* density was > 90% higher in IVs than in up-land maize fields. Chabi-Olaye et al. (2001), using eggs of *B. fusca* and three *Sesamia* spp. as hosts, showed that all four hosts yielded similar levels of parasitism by the sceliotid *Telenomus isis* (Polaszek), egg emergence and sex ratios. In the present study, egg parasitism was up to twofold higher in IVs than in the upland maize fields. These findings suggest that IVs planted with maize during the dry season 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*. Thus, if crops grow concurrently in IVs and upland fields in an area, the chances of emerging borer females to encounter a suitable host plant, e.g., maize, for oviposition and survival of their progenies, and ensuing overall pest densities in an area increase. IVs therefore should be targeted for inundative releases of egg parasitoids against *B. fusca* with the aim of reducing yield losses in adjacent up-land maize fields.

Results from different field trials in Benin and Cameroon where grasses were grown as border rows around maize plots lead to reduced borer densities in such maize fields compared to non-surrounded maize stands (Ndemah et al. 2002). Oviposition and development studies with *S. calamistis* and *E. saccharina* carried out in Benin, using a range of grass species, showed that borers oviposited heavily on grasses (Sekloka 1996; Semeglo 1997; Shanower et al. 1993), but larval mortality was nearly 100% (Shanower et al. 1993). Thus, these grasses acted as trap plants and hence can provide natural control for stem and cob borers. Promising grass species in SSA are among others sudan grass *Sorghum vulgare* var. *sudanense* Hitchc., a commercial fodder grass, molasses grass *Melinis minutiflora* Beauv., a non-host forage plant, and silverleaf desmodium *Desmodium uncinatum* (Jacq.) DC (Khan et al. 1997; 2000). In
West and Central Africa the most reported grass species are *P. purpureum* and *P. maximum* (Innes 1977; Ndemah *et al.* 2002; Schulthess *et al.* 1997).

Recent work in western Africa showed, that maize intercropped with cassava or grain legumes considerably reduced maize yield losses due to *S. calamistis* (Schulthess *et al.* 2004) and *B. fusca* (Chabi-Olaye *et al.* 2005b), as a result of reduced oviposition of adult moths. The value of such cropping systems has been extensively reviewed by Baliddawa (1985) and van Emden and Dabrowski (1994). Overall, these authors concluded that intercropping contributes to the diversity of agro-ecosystems and can reduce population build-up of insect pests. However, not all attempts to control pests through mixed cropping have been successful. Especially the choice of the associated crops and the spatial arrangements for the intercrops is of outmost importance. In our study higher reduction in *B. fusca* oviposition was observed in within row planting compared to strip planting, though both arrangements did not differ in terms of their land-equivalent ratios. Combined maize-cassava crops yielded a higher land-equivalent ratio than maize-legumes. In addition, a study by Sétamou (1999) showed that *M. nigrivenella* preferred jack- and velvetbeans than maize. Thus, with the increasingly popular practice of using cover crops in maize production systems in SSA to improve soil fertility, *M. nigrivenella* populations could greatly increase on these plants, thereby endangering the following maize crop. However, clever timing can produce the opposite effect, i.e., if the emergence of the maize tassels coincides with pods formation on the legumes, as then the attractive pods will cause *M. nigrivenella* to oviposit principally on jack- and velvetbeans (Sétamou 1999).

In our experiments in the humid forest of Cameroon, the leguminous fallow systems and the maize-maize and additional N treatments had significantly higher stem borer densities. However, the borer-induced grain yield losses were considerably lower than in the continuous maize cultivation without additional N fertilization. These results confirm previous findings by Sétamou *et al.* (1995) who hypothesized that an increased nutritional status of the plants enhance both borer fitness and plant vigor, but with a net benefit for the plants. Thus, improving soil fertility can effectively complement pest control.

Results from the presented studies provide an increased understanding of the role of IVs on the population dynamics of maize cob and stem borers in SSA. Moreover, if properly managed, increased crop-plant diversity can considerably reduce the build-up of pest populations and increase the yield of maize, thus becoming an interesting land-use strategy for resource-poor and land-constrained farmers in SSA.

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