

Field boundaries of *Panicum maximum* as a reservoir for predators and a sink for *Chilo partellus*

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Abstract: The biological-control function of field boundaries of Guinea grass, *Panicum maximum* Jacq. on the spotted stem borer, *Chilo partellus* Swinhoe was examined as a reservoir for arthropod predators and as a trap plant for the pest. Field border vegetation and predator density were manipulated to determine the effect of the grass border on the abundance of stem borers and their predators in maize fields, and the effect of predators on the stem borer population. The strip of Guinea grass supported an abundance of earwigs and spiders, the potential predators of stem borer eggs and larvae. Density of *C. partellus* larvae in the Guinea grass strips was low throughout the season and only young larvae were collected, suggesting the inferiority of the grass stand as a habitat for stem borer larvae. These results indicate that Guinea grass is a good agent of habitat management to selectively enhance arthropod predators of stem borers and act as a sink for the pest. Predator removal resulted in a higher density of *C. partellus* than control in maize-bordered plots. On the other hand, no difference was found in the stem borer density between predator treatments in grass-bordered plots, probably because of insufficient predator reduction in removal plots. These results suggest that the predator assemblage found in the study site has, if sufficiently abundant, potential to limit the *C. partellus* population in maize fields. Even though the Guinea grass stand harboured an abundant number of predators, the grass boundaries around maize fields did not enhance predator populations within the crop field. Furthermore, field boundaries of Guinea grass had no measurable effect on the within-field density of *C. partellus* as a trap crop. Creating a polyculture within the crop and early planting of the grass could further enhance the biological-control function of Guinea grass boundaries.

Key words: conservation biological control, field border strips, generalist predators, Guinea grass, stem borer, trap crop

1 Introduction

Grassy field boundaries are a habitat manipulation technique to reduce pest pressure within agricultural fields by exploitation of ecological functions such as predation and plant-herbivore interactions inherent in agroecosystems (Barbosa 1998; Pickett and Bugg 1998; Landis et al. 2000; Gurr et al. 2004). Some plants on the field border act as trap crops that attract, divert, intercept, and retain pest insects, and reduce their density in the main crop (Hokkanen 1991; Shelton and Badenes-Perez 2006). Field border strips can also suppress pest populations indirectly, through enhancing natural enemy abundance, either by providing more niches to occupy, or by increasing the available prey (Landis et al. 2000; Symondson et al. 2002). As Gurr et al. (1998) suggested, these bottom-up (i.e. trap crop) and top-down (i.e. natural enemy) effects of habitat management are not mutually exclusive and are likely to operate together. Nevertheless, the majority of field studies have only focused on these effects separately and few

studies have simultaneously manipulated natural enemy abundance and field border vegetation to determine the impact of these two factors on pest densities.

Numerous plants have been investigated for border planting as trap crops or reservoirs of natural enemies. To enhance natural enemy abundance, the plant stand is appropriate if it provides hibernation sites, refuge from disturbance, and sources of nectar, pollen or alternative prey (Sotherton 1984; Thomas et al. 1992; Lagerlöf and Wallin 1993; Corbett and Rosenheim 1996; Hickman and Wratten 1996; Symondson et al. 2002). However, because borders may also benefit pest populations, plants must be selected with care (Gurr et al. 1998; Landis et al. 2000). That is, attractiveness to pests is an important factor for the success of trap crops (Banks and Ekbom 1999), but plant species must have negative attributes against pest population growth, for instance, unsuitability as larval food sources (Landis et al. 2000; Khan and Pickett 2004; Shelton and Badenes-Perez 2006).

Lepidopterous stem borers, the major pests of cereal crops in Africa, are mostly polyphagous, and have several gramineous and other uncultivated wild host plants (reviewed by Polaszek and Khan 1998). Recent findings indicate that some wild gramineous plants act as trap plants because they are highly attractive to gravid female moths for oviposition, but support poor survival of the larval stages (Khan et al. 1997a, 2006; Mohamed et al. 2004; Atachi et al. 2005; Van den Berg 2006). Trap crop techniques using wild gramineous plants have been developed and are being promoted by various agencies (Khan et al. 1997a, 2001; Kfir et al. 2002; Ndemah et al. 2002). For example, the 'push-pull' strategy based on a combination of a repellent intercrop (the 'push') with a field border trap crop (the 'pull') greatly reduces infestation by the spotted stem borer, *Chilo partellus* (Swinhoe) (Lep., Crambidae) and increases maize grain yields (Khan et al. 2001; Midega et al. 2005a). In this system, the molasses grass (*Melinis minutiflora* Beauv) (Poaceae) used as a repellent intercrop attracts the stem borer larval parasitoid, *Cotesia sesamiae* Cameron (Hym., Braconidae), and increases parasitism rate (Khan et al. 1997b). Generalist predator density is also significantly enhanced in the 'push-pull' fields (Midega and Khan 2003; Midega et al. 2006). Therefore, the top-down effect by parasitoids and predators as well as the bottom-up effect by trap cropping seems to contribute to suppress stem borer density in the 'push-pull' system. Life table studies of *C. partellus* populations indicated that the largest mortality occurred in the egg and young larval stages, the life stages most vulnerable to predation (Oloo 1989; Midega et al. 2005b). It is thus expected that generalist predators would exert a substantial impact on *C. partellus* population, but only a few studies have been conducted to quantify predator impact (Bonhof 1998; Midega et al. 2006).

The objective of the current study was to examine the utility of Guinea grass, *Panicum maximum* Jacq., as an agent for a habitat management strategy to control *C. partellus*. In laboratory choice-tests, the number of eggs oviposited by gravid females of *C. partellus* on maize and Guinea grass did not significantly differ (Mohamed et al. 2004). Meanwhile larval survival on this grass was exceedingly low (Mohamed et al. 2004), implying that Guinea grass can be a possible trap plant for controlling the *C. partellus* population. Furthermore, preliminary research on insect fauna on Guinea grass revealed that a variety of insect predators were present in Guinea grass (Z. R. Khan, unpublished data). Thus, we expected that field border strips of this grass would act as a reservoir of generalist predators and a sink for the stem borer population, if the grass were properly organized in space and time. We manipulated field border vegetation and generalist predator abundance, and tested the following questions: (i) Do Guinea grass strips maintain enhanced populations of arthropod predators? (ii) Is Guinea grass suitable for stem borer oviposition under field conditions? (iii) Can generalist predators act as bio-control agents against *C. partellus* in maize fields? (iv) Can the grassy field border strips enhance predator

abundance within the maize field and suppress stem borer populations?

2 Materials and Methods

2.1 Field site

The field experiment was conducted from April to August 2005 at Wiga, Suba district, western Kenya (0°40'S, 34°12'E and 1320 m above sea level). The site is characterized by a bimodal distribution of rainfall with peaks in May and December, and annual precipitation of approximately 900 mm. The experimental farm was laid out in a 0.8 ha 2-year-old bush fallow, which was burned once and mechanically ploughed twice prior to starting the experiment.

2.2 Experimental design

The field experiment consisted of two factors: field border vegetation and predator removal, arranged in a 2 × 2 factorial design with five replicates, for a total of 20 plots. Each plot was 16 m × 19 m and separated from neighbouring plots by a buffer of 2 m bare ground. A maize field (12 m × 15 m) was located at the centre of each plot, and a 1 m wide strip of land was arranged around the maize field at 1 m intervals from the field perimeter, expanding it by an additional 2 m. For grass border plots, stubble of Guinea grass, containing 10–15 tillers, were cut to a height of 10–15 cm and were planted in three border rows spaced 50 cm between and 30 cm within rows. The field border of control plots was sown with maize seeds in the same arrangement. Each of the predator removal plots was enclosed with a wall of sheet metal flashing reaching 10 cm into the soil and projecting 40 cm over the surface. The top of the fence was coated with Tangletrap (Tanglefoot Co., Grand Rapids, MI), to limit the movement of non-flying arthropods. Ground-dwelling predators were removed with pitfall traps, which operated nine times from April to June. Twenty-two plastic cups (500 ml, diameter 10 cm and depth 10 cm), partly filled with water were placed at 3-m intervals along the inner wall of the fence of each removal plot. One day after trap setting, predators captured in these traps were removed and all other animals were returned into the enclosures. Additionally, predators on the plant surface were removed manually seven times during April and June. For each removal plot, all plants in every second row of the maize field and those in the first row of each side of the field border strip were carefully inspected and arthropod predators were removed with a pooter. For Guinea grass plants, predators were also removed by the beating method (Sutherland 1996). After inspection, each plant was tapped for 10 s with a wooden stick, and dislodged arthropod predators were caught in a tray (30 cm × 20 cm, depth 10 cm) held at the lower part of the plant.

Within the field, maize (Western Seed, Hybrid 502) was sown with a spacing of 75 cm between and 30 cm within rows. Maize and Guinea grass were planted between 25 March and 1 April, 2005. Plots were weeded at 14 and 35 days after the planting.

2.3 Sampling protocol

Sampling was done five times at key phenological stages of maize, viz. vegetative (April–May), flowering (early June) and maturing (early July) stages. The predator densities in the field border strip and in the maize field were determined

by using the following procedure. For each plot, one row from one side of the plot border (containing approximately 40–80 plants) and one other row from the field interior (containing approximately 40–70 plants) were selected at random. All plants of the rows were carefully inspected for predatory arthropods. The arthropods were collected with a pooter and preserved in 70% ethanol. For all samples taken, potential predators of *C. partellus* eggs and larvae were defined based on the records by Bonhof (1998) and Midega and Khan (2003), and identified to species or morphospecies whenever possible. Number of plants examined was recorded and predator density per 100 plants was obtained.

The density of stem borer larvae was determined from destructive sampling of the plants, responsible for the high variation in plant density in the fields. For each plot, 20 plants, each from the field border strips and field interior, were randomly selected and uprooted. In the laboratory, plant height and stage were recorded and the number of tillers was also recorded for Guinea grass. Leaf sheaths, ears and ear husks of sampled plants were carefully removed and searched for eggs and larvae of *C. partellus*, and then stalks were split to locate larvae and pupae, both live and dead. Live larvae and pupae were reared individually with maize stalks in a Petri dish (9 cm diameter, 1.5 cm depth) until they emerged as adults or died. As egg density was not sufficient and there was insignificant difference in seasonal change in density of different larval instars, the data for all larval stages was pooled for analysis. The parasitoids that emerged were preserved in 70% ethanol and identified to species. The parasitism rate was calculated for each plot with cumulative number of larvae over five sampling dates. All voucher specimens were deposited at the National Museum of Kenya and at the biosystematics unit of the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

2.4 Data analysis

Densities of predators and *C. partellus* larvae were analysed by repeated measures analysis of variance (ANOVA), with grass border and predator removal as between-subject factors and sampling date as the within-subject factors (Zar 1999). Data was transformed using $\log_{10}(x + 1)$ to stabilize variances. Where there was a significant interaction between grass border and predator removal, the least significant difference (LSD) test was applied to test for differences in mean densities between treatment and control for each factor. Where date and field border planting, or date and predator exclusion interactions occurred, a two-factor ANOVA stratified by date was performed to determine statistical differences in factor effects on each sampling date. Probability values in the stratified analyses were adjusted by the Bonferroni procedure. Plant height and parasitism rate were analysed by two-factor ANOVA. Data was $\log_{10}(x + 1)$ - and arcsine-transformed prior to analysis for the plant height and parasitism rate, respectively. All statistical analyses were performed using the SPSS statistical package (version 10.0, SPSS Inc., Illinois, USA).

3 Results

3.1 Plant growth in the field border strips

Maize and Guinea grass showed a largely similar pattern in the phenology of shoot growth (fig. 1). Plants grew rapidly from April to July and reached approximately 2 m in height. Maize bloomed from mid May to June, while Guinea grass bloomed from mid

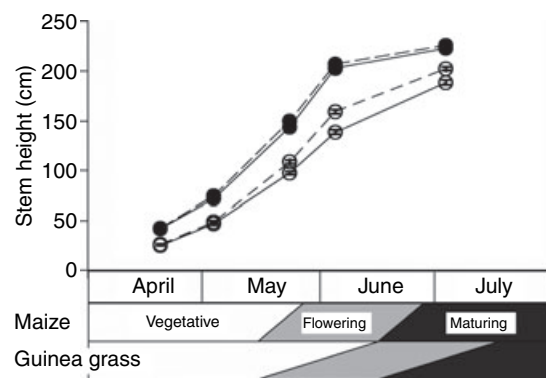


Fig. 1. Seasonal changes in mean (\pm standard error) stem height and schematic representation of growth stages of maize (●) and Guinea grass (○). Solid and broken lines show plants in non-removal and removal plots, respectively

May to mid July. The full height of plants was higher in maize than in Guinea grass and not significantly different between predator removal and control plots (two-way ANOVA: plant species, $F_{1,2009} = 45.36$, $P < 0.01$; predator removal, $F_{1,2009} = 3.19$, $P > 0.05$; plant species \times predator removal, $F_{1,2009} = 1.52$, $P > 0.05$).

3.2 Predator removal

From predator removal plots, 19 460 ants (Hym., Formicidae), 1317 spiders (Araneae), 693 carabids (Col., Carabidae), 246 rove beetles (Col., Staphylinidae), 302 predatory bugs (Het., Anthocoridae; Reduviidae and Lygaeidae), 23 coccinellids (Col., Coccinellidae), 18 anthicids (Col., Anthicidae) and four earwigs (Derm: Forficulidae) were removed with pitfall traps on nine dates from April to July. Another 6701 potential predator arthropods were removed manually on seven dates during April and July. These were dominated by the ants, 2940, with the other groups distributed as follows: 1363 spiders, 900 earwigs, 794 coccinellids, 477 anthicids, 80 predatory bugs, 77 rove beetles, 29 larvae of lacewings (Neurop., Chrysopidae), 22 carabids and 14 Melyrids (Col., Melyridae).

3.3 Predators in the field border strips

A total of 2254 individuals from 46 species/morphospecies of insect predators and 388 individuals from 17 families of spiders were found in the field border strips over five sampling dates. The most numerous predator groups were ants (46.6%), earwigs (25.5%) and spiders (14.7%). Spiders consisted of Araneidae (45.6%), Lycosidae (16.5%), Oxyopidae (7.2%), Thomisidae (7.0%), Salticidae (5.9%), Miturgidae (3.4%), Pisauridae (3.1%), Philodromidae (2.3%), Theridiidae (2.1%) and other eight families (7.0%). The most frequent insect species/morphospecies are listed in table 1.

Densities of all the predator assemblage were significantly affected by field border vegetation (table 1). Densities differed among sample dates ($F_{4,64} = 4.38$,

Table 1. Mean densities of dominant insect predators and spider guilds (a) and main predator groups (b) on field border strips of each experimental plot

Predators	Species/guild	Individuals per 100 plants ¹						Source ²			
		Treatment			Border (Bo)			Predator (Pr)		Bo × Pr	
		Maize + non-removal	Maize + removal	Grass + non-removal	Grass + removal	$F_{1,16}$	P	$F_{1,16}$	P	$F_{1,16}$	P
(a) Dominant species											
Ants	<i>Tetramorium</i> sp. 1	10.94 ± 6.94	9.15 ± 3.62	9.20 ± 1.68	9.99 ± 3.73	0.86	0.37	0.10	0.76	0.15	0.71
	<i>Camponotus</i> sp. 1	15.58 ± 4.60	4.69 ± 1.01	3.02 ± 0.89	1.79 ± 0.44	16.16	<0.01	6.35	0.02	2.01	0.18*
	<i>Camponotus</i> sp. 3	5.95 ± 1.26	5.32 ± 0.93	5.26 ± 1.19	4.02 ± 1.16	0.63	0.44	0.25	0.62	0.19	0.67
	<i>Odontomachus</i> sp. 1	1.59 ± 0.43	0.49 ± 0.21	1.27 ± 0.54	2.56 ± 0.74	2.62	0.13*	0.14	0.71	5.36	0.03*
	<i>Dorylus</i> sp. 1	0.00 ± 0.00	3.91 ± 4.00	1.83 ± 1.03	0.00 ± 0.00	0.27	0.61	0.27	0.61	3.23	0.09
Earwigs	<i>Diaperasticus erythrocephalus</i>	12.23 ± 5.16	3.09 ± 0.75	19.56 ± 8.35	5.08 ± 1.96	0.20	0.66*	7.48	0.01	0.67	0.43
	<i>Forficula senegalensis</i>	3.39 ± 1.28	0.76 ± 0.34	5.58 ± 1.88	7.91 ± 3.68	10.75	<0.01*	1.98	0.18	3.64	0.07
Anthicids	<i>Formicomus</i> sp. 2	0.00 ± 0.00	0.55 ± 0.23	3.05 ± 0.78	4.72 ± 1.07	37.44	<0.01*	2.71	0.12	0.001	0.97
Coccinellids	<i>Scymnus</i> spp.	1.93 ± 0.54	2.87 ± 0.84	0.81 ± 0.34	0.40 ± 0.20	14.28	<0.01	0.02	0.89	1.28	0.27
Spiders ³	Free living ⁴	1.45 ± 0.30	3.27 ± 0.73	6.05 ± 1.21	6.13 ± 1.15	20.42	<0.01	3.55	0.08	1.29	0.27
	Orb weavers ⁵	1.95 ± 0.49	1.39 ± 0.40	6.17 ± 1.18	7.87 ± 1.50	43.05	<0.01*	0.08	0.78	2.13	0.16
(b) Predator groups											
All predators		59.07 ± 11.35	40.81 ± 7.27	80.31 ± 12.62	58.82 ± 7.45	25.91	<0.01*	9.83	0.01*	0.09	0.77
Ants		34.43 ± 8.69	24.16 ± 5.70	23.00 ± 4.14	19.46 ± 4.27	1.70	0.21	2.34	0.15	0.10	0.76
Earwigs		16.19 ± 6.52	4.13 ± 0.97	34.19 ± 13.27	14.64 ± 5.67	3.18	0.09*	7.78	0.01	0.07	0.79
Spiders		3.69 ± 0.75	4.85 ± 0.74	12.61 ± 1.94	14.58 ± 2.07	46.67	<0.01*	3.52	0.08	0.03	0.88
Others ⁶		4.75 ± 1.07	7.67 ± 2.39	10.52 ± 1.78	10.15 ± 1.64	11.68	<0.01*	0.13	0.72	0.13	0.73

¹Treatment means (± standard error; $n = 25$) over five sampling dates.²Repeated measures ANOVA. For brevity, date effects are not included in the table and significant effects are reported in the text.³Guilds after Dippenaar-Schoeman and Jocqué (1997).⁴Mostly Lycosidae, Oxyopidae, Thomisidae, Salticidae, Miturgidae, Pisauridae and Philodromidae.⁵Mostly Araneidae.⁶Coccinellidae, Anthicidae, Staphylinidae, Anthocoridae, Lygaeidae, Reduviidae, Syrphidae (larvae), Chrysopidae (larvae), Melyridae and Carabidae.*Indicates a significant date by the factor interaction ($P < 0.05$).

$P < 0.01$), and there was a significant interaction between field border planting and sample date ($F_{4,64} = 5.14$, $P < 0.01$). Predator densities were higher in Guinea grass strips compared with maize strips in early June ($F_{1,16} = 20.38$, $P < 0.01$) and early July ($F_{1,16} = 17.01$, $P < 0.01$) (fig. 2). Ant densities did not significantly differ between maize and Guinea grass (table 1). The same was observed for the five dominant ant morphospecies, except for *Camponotus* sp. 1 which showed a higher density in maize than in Guinea grass (table 1). Ants differed in density among sample dates ($F_{4,64} = 4.22$, $P < 0.01$) and colonized the field earlier than the other predator groups (fig. 2). The densities of earwigs were affected by field border vegetation (table 1) and differed among sample dates ($F_{4,64} = 30.18$, $P < 0.01$). Adult earwigs colonized the strips at vegetative stages, and nymphs emerged and increased quickly from flowering to maturing stages. There was a significant interaction between date and field border planting ($F_{4,64} = 13.02$, $P < 0.01$), indicating higher densities in Guinea grass in early June ($F_{1,16} = 69.34$, $P < 0.01$) and early July ($F_{1,16} = 18.66$, $P < 0.01$) (fig. 2). Two species of earwigs, *Diaperasticus erythrocephalus* (Olivier) and *Forficula senegalensis* Serville (both Derm.: Forficulidae), were more numerous in Guinea grass strips, although these differences were only statistically significant for *F. senegalensis* (table 1). Spider densities were significantly affected by field border planting (table 1). Densities differed among sample dates ($F_{4,64} = 2.97$, $P = 0.03$), and there was a significant interaction between field border planting and sample date ($F_{4,64} = 5.73$, $P < 0.01$). Spider densities were higher in Guinea grass strips compared with maize strips later in the season (early June, $F_{1,16} = 35.93$, $P < 0.01$; early July, $F_{1,16} = 38.09$, $P < 0.01$) (fig. 2). Similarly, both spider guilds (free living and orb weavers) showed higher densities in Guinea grass strips compared with maize strips (table 1). Densities of other predator groups were affected by field border planting (table 1), and field border planting \times sampling date interaction ($F_{4,64} = 12.30$, $P < 0.01$). Densities were

higher in Guinea grass strips in early June ($F_{1,16} = 51.01$, $P < 0.01$) and early July ($F_{1,16} = 17.01$, $P < 0.01$). The same tendency was observed for *Formicomus* sp. 2 (Col., Anthicidae) (table 1). On the other hand, *Scymnus* spp. (Col., Coccinellidae) was abundant in maize strips throughout the season (table 1).

By intensive removal with pitfall trapping and hand searching, densities of the predator assemblage were significantly reduced in the removal plots compared with control plots (table 1). The same was observed for earwigs, but there were no significant differences in densities of ants, spiders and other predator groups.

3.4 Predators in the maize field

In total, 1479 individuals from 31 species/morphospecies of insect predators and 224 individuals from 17 families of spiders were found in the maize fields over five sampling dates. The most numerous predator groups were ants (50.5%), earwigs (17.1%) and spiders (13.2%). Spiders consisted of Araneidae (56.3%), Lycosidae (8.5%), Oxyopidae (8.5%), Salticidae (5.8%), Theridiidae (4.5%), Thomisidae (4.0%), Mirturgidae (4.0%) and other 10 families (8.5%). The dominant insect species/morphospecies are listed in table 2.

The field border vegetation had neither an effect on densities of all predators, any specific species, nor guilds (table 2). Averaged over five sampling dates, the removal of arthropod predators led to a 17.7% and 33.0% decrease in total predator densities for grass- and maize-bordered plots, respectively (table 2). However, our ability in removal was variable for different predator groups. Over the season, ant densities in removal plots were 18.1% and 33.8% lower than control plots for grass- and maize-bordered plots, respectively, although removal effect was only marginally significant (table 2, fig. 3). Of the five dominant ants, only *Camponotus* sp. 1 showed a significant difference in density between removal and control

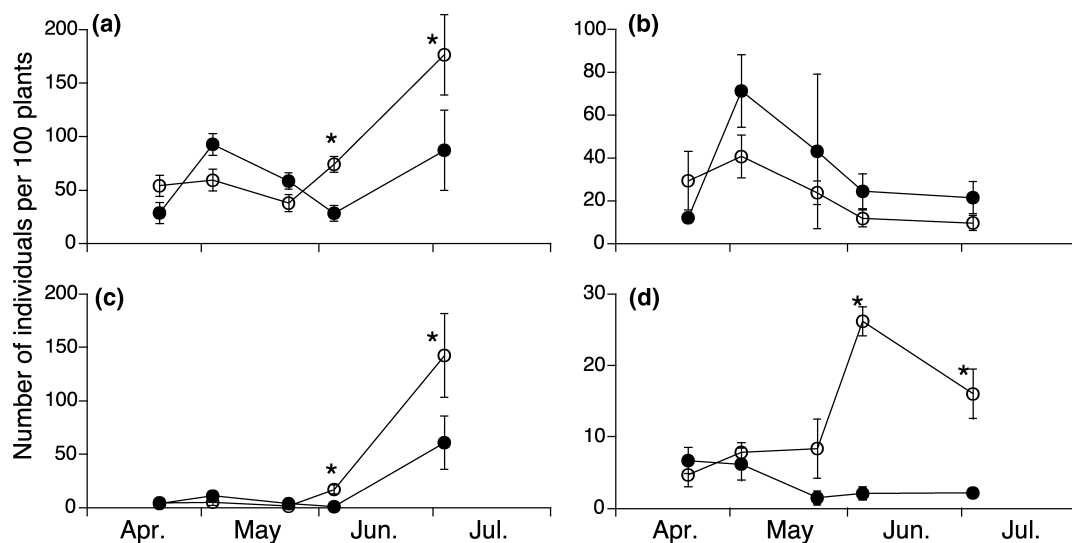


Fig. 2. Unmanipulated densities of all arthropod predators (a), ants (b), earwigs (c) and spiders (d) in field border strips. Means (\pm standard error) are shown. For periods with an asterisk, a significant difference was detected between maize (●) and Guinea grass (○) strips (ANOVA, $P < 0.01$ after Bonferroni correction)

Table 2. Mean densities of dominant insect predators and spider guilds (a) and main predator groups (b) within crop fields of each experimental plot

Predators	Species/guild	Individuals per 100 plants ¹						Source ²								
		Treatment			Border (Bo)			Predator (Pr)			Bo × Pr					
		Maize + non-removal	Maize + removal	Grass + non-removal	Grass + removal	F _{1,16}	P	F _{1,16}	P	F _{1,16}	P	F _{1,16}	P			
(a) Dominant species																
Ants	<i>Camponotus</i> sp. 1	7.94 ± 1.57	3.81 ± 1.22	12.24 ± 2.53	5.04 ± 2.00	0.56	0.46*	10.36	0.01	0.003	0.96*					
	<i>Camponotus</i> sp. 3	4.55 ± 0.90	5.50 ± 1.09	7.04 ± 1.43	6.99 ± 2.08	0.26	0.62	0.24	0.63	0.54	0.47					
	<i>Tetramorium</i> sp. 1	4.15 ± 1.69	1.17 ± 0.53	2.12 ± 0.89	5.59 ± 3.20	0.12	0.73	0.71	0.41	1.57	0.23					
Earwigs	<i>Odontomachus</i> sp. 1	2.51 ± 1.01	1.57 ± 0.79	1.02 ± 0.47	1.02 ± 0.51	0.85	0.37	0.17	0.69	0.04	0.84					
	<i>Diaperasticus erythrocephalus</i>	5.53 ± 1.86	4.71 ± 2.02	4.57 ± 1.56	2.16 ± 0.75	1.50	0.23	2.90	0.11	0.007	0.93					
	<i>Forficula senegalensis</i>	1.86 ± 0.77	0.38 ± 0.22	1.72 ± 0.92	1.93 ± 0.92	0.67	0.42	1.53	0.23	2.44	0.14					
Coccinellids	<i>Scymnus</i> spp.	3.68 ± 0.65	2.53 ± 0.68	3.33 ± 0.92	3.35 ± 0.74	0.04	0.85	0.39	0.54	2.21	0.16					
Syrphids	Syrphidae spp.	3.29 ± 1.68	2.30 ± 1.41	1.01 ± 0.76	1.59 ± 1.23	1.51	0.23	0.08	0.77	0.18	0.68					
Spiders ³	Free living ⁴	2.10 ± 0.56	1.84 ± 0.55	1.76 ± 0.64	1.50 ± 0.42	0.48	0.50	0.06	0.81	0.38	0.55					
	Orb weavers ⁵	4.51 ± 1.85	1.75 ± 0.48	2.49 ± 0.66	3.24 ± 1.04	0.01	0.91	0.36	0.55	0.78	0.39					
(b) Predator groups																
All predators		44.33 ± 4.50	29.66 ± 2.48	45.05 ± 4.88	37.06 ± 6.89	0.002	0.96	8.86	0.01	0.007	0.93					
Ants		20.14 ± 2.88	13.31 ± 1.93	23.17 ± 3.25	19.05 ± 4.70	0.13	0.72*	3.84	0.07	0.05	0.84*					
Earwigs		7.84 ± 2.64	5.38 ± 2.12	9.61 ± 3.52	5.80 ± 2.25	0.46	0.51	3.18	0.09	0.03	0.87					
Spiders		7.05 ± 2.00	3.59 ± 0.75	4.82 ± 1.06	5.04 ± 1.28	0.001	0.98	0.34	0.57	0.79	0.39					
Others ⁶		9.30 ± 2.03	7.37 ± 2.01	7.46 ± 1.85	7.17 ± 1.60	0.00	0.99	0.61	0.45	0.83	0.38					

¹Treatment means (± standard error; n = 25) over five sampling dates.²Repeated measures ANOVA. For brevity, date effects are not included in the table and significant effects are reported in the text.³Guilds after Dippenaar-Schoeman and Jocqué (1997).⁴Mostly Lycosidae, Oxyopidae, Thomisidae, Salticidae, Miturgidae, Pisauridae and Philodromidae.⁵Mostly Araneidae.⁶Coccinellidae, Anthicidae, Staphylinidae, Anthicoridae, Lygaeidae, Reduviidae, Syrphidae (larvae), Chrysopidae (larvae), Melyridae and Carabidae.

*Indicates a significant date by the factor interaction (P < 0.05).

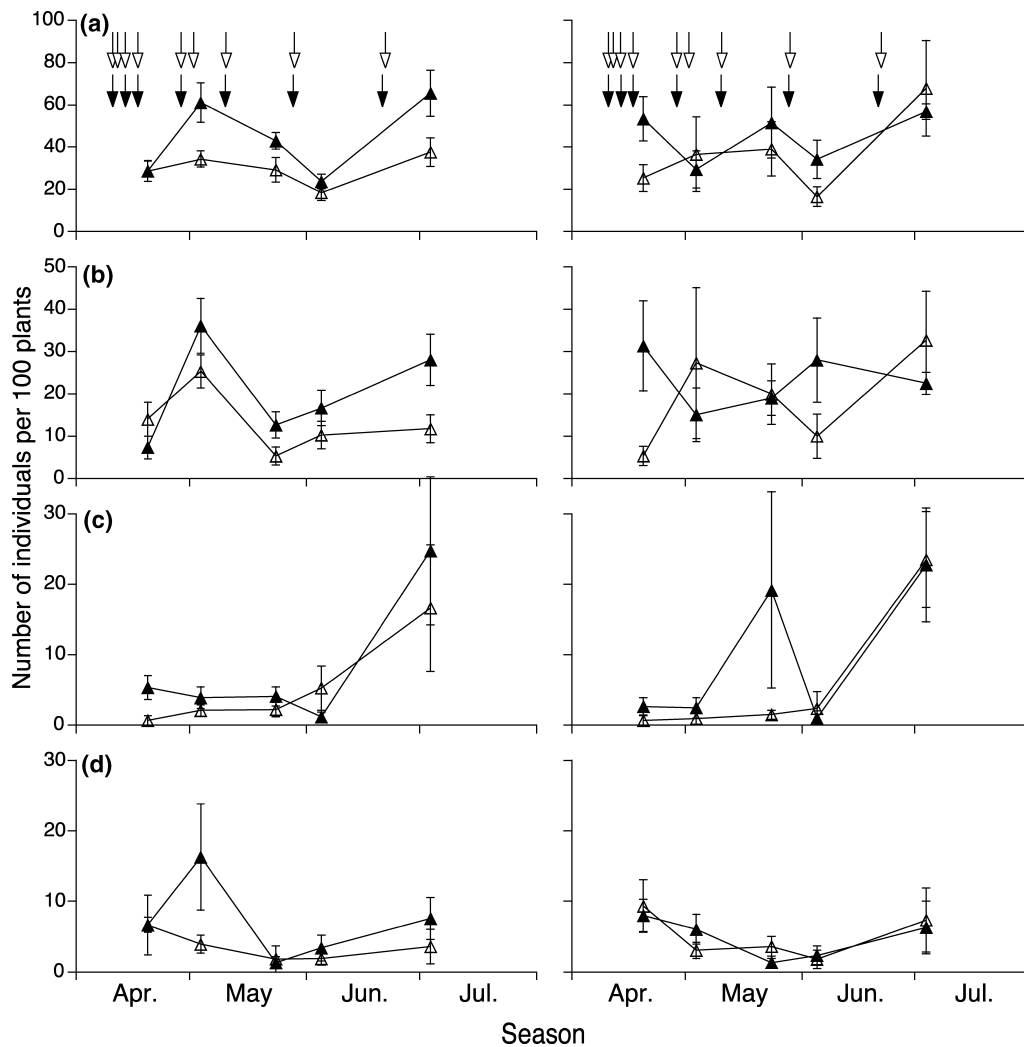


Fig. 3. Mean (\pm standard error) densities of all arthropod predators (a), ants (b), earwigs, (c) and spiders (d) within crop field of removal plots (Δ) and non-removal plots (\blacktriangle). Left: maize-bordered plots. Right: Guinea grass-bordered plots. Black and white arrows indicate date of the removal by hand searching and by pitfall traps, respectively

plots. Earwig densities in removal plots compared with control plots were 39.6% and 30.8% lower for grass- and maize-bordered plots, respectively (table 2). The same tendency was observed for the two predominant species, *D. erythrocephalus* and *F. senegalensis*, although these differences were not statistically significant. Contrary to ants and earwigs, spider density was unaffected by the removal treatment (table 2). This was evident when spider density was broken down into free living or orb weavers guilds. Date effect was significant for every predator group (all predators, $F_{4,64} = 8.05$, $P < 0.01$; ants, $F_{4,64} = 3.69$, $P = 0.02$; earwigs, $F_{4,64} = 14.89$, $P < 0.01$; spiders, $F_{4,64} = 6.50$, $P < 0.01$; others, $F_{4,64} = 9.15$, $P < 0.01$) (fig. 3), but there was no significant interaction with either field border vegetation or predator removal.

3.5 Stem borers

One full generation and a partial second generation of *C. partellus* occurred in a cropping season, with peak density in early May (date effects: field border strips, $F_{4,64} = 19.43$, $P < 0.01$; maize field, $F_{4,64} = 22.53$,

$P < 0.01$) (fig. 4). In the Guinea grass strips, stem borer density was low throughout the season (fig. 4a), and only first to third instar larvae were collected. The density in maize strips was higher in enclosed plots than control plots, but this difference was not statistically significant (fig. 4a, table 3). In the maize fields, effects of the field border vegetation and the predator removal treatment on the stem borer density were insignificant, but a border \times predator interaction was found (table 3). Mean comparisons revealed no differences in the stem borer density between maize- and grass-bordered fields in both removal and control plots (LSD test: $P > 0.05$) (fig. 4b). On the other hand, stem borer density was higher in removal than control plots in maize-bordered fields (LSD test: $P = 0.02$) (fig. 4b). The density of *C. partellus* larvae was not significantly different between predator treatments in grass-bordered fields (LSD test: $P > 0.05$) (fig. 4b).

Parasitism of *C. partellus* larvae, mostly by *Cotesia flavipes* Cameron (Hym., Braconidae), was not affected by field border vegetation or predator removal (two-way ANOVA: $P > 0.80$) and remained at relatively low levels from $13.4 \pm 6.3\%$ to $15.1 \pm 21.1\%$.

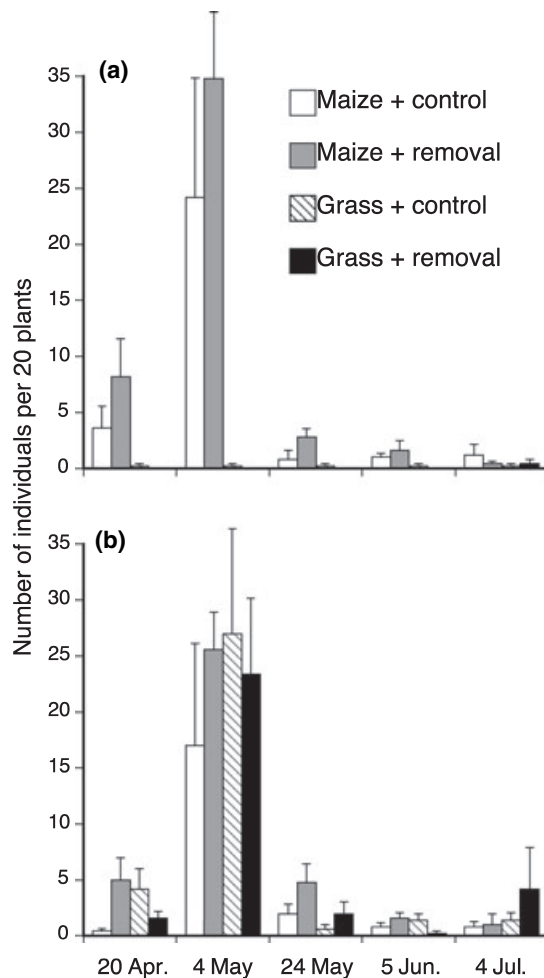


Fig. 4. Mean (\pm standard error) densities of *Chilo partellus* larvae in field border strips (a) and within crop field (b)

Table 3. Repeated measures analysis of variance table of field border vegetation and predator removal effects on the density of *Chilo partellus* larvae in field border strips and crop field

Source ¹	d.f.	MS	F	P
Field border				
Border	1	6.830	83.943	<0.001
Predator	1	0.130	1.601	0.224
Border \times predator	1	0.321	3.944	0.064
Error	16	0.081		
Crop field				
Border	1	0.020	0.194	0.665
Predator	1	0.266	2.583	0.128
Border \times predator	1	0.524	5.085	0.038
Error	16	0.103		

¹For brevity, date effects are not included in the table. Significant effects are reported in the text.

4 Discussion

4.1 Predators and stem borers in the field border strips

The strips of Guinea grass harboured an abundance of arthropod predator populations, but the effect was variable for different predator groups: the grass strips

supported higher abundance of earwigs and spiders relative to the maize strips, while ant density was similar in the grass and maize strips. Densities of two earwig species, *D. erythrocephalus* and *F. senegalensis* increased quickly in the flowering and maturing stages of the plants, and a large number of their larvae were observed during these periods. By gut dissections of *F. senegalensis* on millet, Boukary et al. (1997) found that the larvae of the earwigs mainly consumed pollen while adults preyed on pollen and animal matter such as aphids and lepidopteran larvae. The high density of earwigs in the Guinea grass strips may thus suggest that the grass provides a superior source of pollen, the main component of larval diet, and improved survival and development of earwig larvae. The Guinea grass strips also supported a higher abundance of spiders. There is a large body of evidence showing that uncultivated strips often increase spider density by serving as a refuge with a high structural and microclimate complexity and alternative prey (reviewed in Sunderland and Samu 2000). The Guinea grass plant clearly has more complex foliage structure than maize, but the mechanisms underlying spider augmentation are unknown.

Density of *C. partellus* larvae in the Guinea grass strips was low throughout the season. Only young larvae were collected from Guinea grass strips, and older larvae and pupae were not observed. This confirmed that *C. partellus* moths oviposited on Guinea grass under field conditions. The high predator populations in the Guinea grass border seemed to have appreciably reduced *C. partellus* populations in the grass. Considering the low developmental performance of *C. partellus* larvae on Guinea grass (Mohamed et al. 2004), this indicates the inferiority of the grass stand as a habitat of stem borer larvae. These results indicate that Guinea grass is a good candidate as an agent of habitat management to selectively enhance arthropod predators of stem borers while inhibiting rapid growth and development of the pests.

4.2 Predation effect on the stem borer population

There is growing evidence from field experiments that assemblages of arthropod generalist predators can serve as biocontrol agents against pest insects in various agricultural crops (reviewed in Symondson et al. 2002). For the control of maize stem borers in Africa, many authors have suggested the importance of predators (reviewed in Bonhof 1998). Nevertheless, few studies have been conducted to quantify predator impact. Kfir (2002) found the regulation of *C. partellus* population by parasitoids and predators in insecticide exclusion experiments. Similar observations were also made by Midega et al. (2006) in predator exclusion studies. In the current studies, overall, generalist predators failed to suppress stem borer populations, but the multiple comparison tests for maize- and grass-bordered plots revealed predator impacts only in maize-bordered plots. In these plots, stem borer density was higher in predator removal than non-removal plots. This could be attributed to the differences in abundance of predators, mainly ants and

earwigs, between removal and non-removal plots, as parasitism rates by *C. flavipes* were similar in both treatments. Many studies have reported that ants and earwigs preyed on eggs and young larvae of *C. partellus* in field observations and laboratory feeding trials (Oloo 1989; Dwumfour et al. 1991; Bonhof 1998; Midega and Khan 2003). Therefore, both of these predator groups presumably reduced stem borer abundance in the non-removal treatments. More detailed studies are however necessary to assess the relative importance of ants and earwigs for control of stem borer populations.

In contrast, the impact of predator removal on stem borer density was not found in grass-bordered plots. Predator removal in grass-bordered plots achieved only a 17.7% reduction in predator density in removal plots compared with non-removal plots. On the other hand, in the maize-bordered plots, where predator removal resulted in a significant increase in stem borer densities, predator density in removal plots was reduced by up to 33.0% compared with that in non-removal plots. It is therefore likely that a difference in predator densities in excess of 30% would be needed for a measurable impact on stem borer populations. The generality of this conclusion needs further investigation using field experiments with different levels of predator density.

4.3 Effect of field border strips on predators and stem borers in the crop field

Despite the fact that the Guinea grass stand harboured an abundant number of arthropod predators, field border grass strips did not enhance predator populations within the crop field. This indicates that high numbers of predators in the field border strips have not necessarily been inclined to move to the adjacent maize crop, as several studies showed predator abundance in cereal crops decreased with increasing distance from grassy field borders, field margin or hedges (Dennis and Fry 1992; Jmhasly and Nentwig 1995; Fournier and Loreau 1999; Mensah 1999; Denys and Tscharrntke 2002). In the 'push-pull' field using a Napier grass (*Pennisetum purpureum* Schumach) field border with a desmodium (*Desmodium uncinatum* Jacq.) intercrop, the abundance of ants, earwigs and spiders in crop field was higher than those in maize monoculture (Midega and Khan 2003). In this case, habitat diversification within the field by the intercropping might encourage predator movement from grassy field borders to the crop. Creating a polyculture within the maize crop by use of a suitable intercrop would be one such option that might encourage movement of the predators from the Guinea grass border into the maize field.

It is acknowledged that a 2-m wide buffer between experimental plots in this study might have been insufficient to prevent arthropod dispersal among plots. Guinea grass strips might enhance predator densities not only in grass-bordered fields but also in adjacent maize-bordered fields. The plot arrangement might have therefore obscured any differences in predator densities between grass- and maize-bordered fields.

In this study, field border strips of Guinea grass had no measurable effect on the within-field density of *C. partellus*, as a trap crop or a reproductive sink. In contrast, Ndemah et al. (2002) studied the effect of field border strips of several wild grasses in Benin, and found Guinea grass strips lowered the population of stem borer, *Sesamia calamistis* Hampson (Lep., Pyralidae) in the maize crop. There are several possible explanations for the different results of the two studies. First, Guinea grass was more attractive than maize for the reproductive moths of *S. calamistis* in greenhouse trials (Schulthess et al. 1997) and in field experiments (Ndemah et al. 2002), while it was less attractive than maize for the moths of *C. partellus* in a laboratory choice-test (Mohamed et al. 2004). In this study, the attractiveness of Guinea grass for stem borer oviposition was unknown because an insufficient number of eggs were sampled, but it is likely that low oviposition preference of *C. partellus* for Guinea grass resulted in low efficiency of the grass as a trap crop. Secondly, the *S. calamistis* population in Benin was subjected to high parasitism of eggs and larvae, and parasitism rates were higher in maize surrounded by Guinea grass than in a pure maize crop (Ndemah et al. 2002), while in this study larval parasitism was generally low and not affected by field border vegetation. Different levels of parasitism in grass-bordered maize crops might cause inconsistent results for the effect of Guinea grass strips on *S. calamistis* and *C. partellus* populations. Finally, Guinea grass was planted 2 weeks prior to maize planting in the experiment in Benin, while the grass and maize were planted at the same time in this study. In this study, the grass plants were smaller than the maize plants throughout the cropping season, and thus might be less attractive for moth oviposition. Furthermore, as Ndemah et al. (2002) suggested, early planting of the grass in the experiment in Benin facilitated the carry-over of natural enemy populations from one cropping season to the next. However, in this study, predator population enhancement was observed substantially after the peak of stem borer reproduction, and thus possibly made limited impact on stem borer populations.

Several theoretical and field studies suggest that initial predator density is one of the most important factors in determining efficacy of natural enemies for pest control (Holland et al. 1996; Landis and van der Werf 1997; Wiedenmann and Smith 1997). To develop effective control strategies for *C. partellus*, predators should be established in the maize field early in the cropping season, when stem borer larvae are vulnerable to predation. For this purpose, the support of predator populations during the fallow period preceding maize planting is crucial to fully exploit their effect on crop pests. For example, leaving strips of Guinea grass after the previous maize harvest may provide a suitable habitat and resource for arthropod predators during the fallow period, enabling them to reproduce and be carried over from one cropping season to another. Such a farming scheme could further promote and benefit from naturally occurring arthropod predators on Guinea grass strips.

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