Bulletin of Entomological Research (2005) **95**, 417–427 DOI: 10.1079/BER2005373

Relationships of intercropped maize, stem borer damage to maize yield and land-use efficiency in the humid forest of Cameroon

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Abstract

Stem borers are the most important maize pests in the humid forest zone of Cameroon. Field trials were conducted 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 tunnelled and 1.3–3.1 times more cob damage than intercrops. Each percentage increase in stem tunnelling lowered 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 per plant, 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 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 cropping this system is thus recommended for land-constrained poor farmers who do not use external inputs such as fertilizer and insecticides.

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Keywords: stem borers, Cameroon, maize, yield loss, intercropping, land-use efficiency, cassava, cowpea, soybean

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 up to 2000 m a.s.l. in the highlands. 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 sub-Saharan Africa, maize is attacked by a complex of stem and cob borer species belonging to the families 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 & Mareck, 1991; Cardwell *et al*., 1997; Sétamou *et al*., 2000), and are aggravated by the poor nutritional status of the plant (Sétamou *et al*., 1995; Chabi-Olaye *et al*., 2005b). Maize yield can be reduced by 10–100% depending on the season (Cardwell *et al*., 1997; Ndemah & Schulthess, 2002).

Many studies in tropical as well as temperate zones reported low pest densities in diversified systems (Altieri & Letourneau, 1982; Risch *et al*., 1983; Andow, 1991; Thies & Tscharntke, 1999; Kruess & Tscharntke, 2000). In Africa, such techniques include pest diversion or trap cropping (Khan *et al*., 1997; Ndemah *et al*., 2002) and mixed cropping (Litsinger & Moody, 1976; Okigbo & 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* (Chabi-Olaye *et al*., 2005a), 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

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- to 6-year-old bush fallow dominated by *Chromolaena odorata* (L.) King & Rob. (Asteraceae). The site is characterized by a bimodal distribution of rainfall, with peaks in June and September and an annual precipitation of about 1500 mm. The long and short rainy seasons last from mid-March to mid-July and from mid-August to the 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 February. Rains started early in 2002 compared to 2003 and peaked in April (195 mm) and October (438 mm). In 2003, rainfall peaked in July (275 mm) and October (689 mm). 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 seasons.

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 plants. Two spatial arrangements were used in mixed cropping: (i) a 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 two rows of a non-maize crop, with one row of non-host plant as 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 insecticide treatment. All treatments were arranged in a randomized complete 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 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 *c*. 1.5 a.i. kg ha^{-1} by placing the granules in the whorl. The plots were kept weed-free.

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

https://doi.org/10.1079/BER2005373 Published online by Cambridge University Press

Table 1. Planting patterns and plant populations (plants ha^{-1}) in monocrops and intercrops.

Treatments	Planting pattern		Seeds/cuttings per hill		Plants ha^{-1}	
	Maize	Associated crop	Maize	Associated crop	Maize	Associated crop
Maize-monocrop	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

Ah, alternate hill; Ar, alternate row.

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 days after planting, soybean and maize at 110, and cassava at 365 days after planting. Each plot was divided into four quadrants, and a predetermined sub-plot of 3 m^2 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 analysed 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. The total root dry matter was estimated by multiplying the fresh root weight with the proportion of dry matter.

Statistical analysis

The egg-to-larva mortalities were estimated 42 and 63 days after planting. To this end, the total numbers of larvae collected at 42 or 63 days after planting were divided by the cumulative numbers of eggs collected up to 35 or 56 days after planting, respectively, a method described in detail in Chabi-Olaye *et al*. (2005a). The analyses were done separately for each cropping season. Differences in plant height, total dry matter, grain weight, mortalities and damage variables were analysed 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. Least significant differences (LSD) were computed for crop yields. 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 & 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 & Willey (1980), the land-equivalent-ratio 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 land-equivalent-ratio is >1, the intercrop is more efficient in terms of land use and if it is <1 the monoculture is more efficient.

Table 2. Effects of maize intercropped with different non-host crops in alternate hills and alternate rows on the least square means of number of *Busseola fusca* per plant at different days after planting during the long and short rainy seasons of 2002 and 2003.

Treatments	Growing season							
	Long rainy season				Short rainy season			
	28 DAP	42 DAP	56 DAP	70 DAP	35 DAP	49 DAP	63 DAP	77 DAP
2002								
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
S.E.	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
	35 DAP	49 DAP	63 DAP	77 DAP	28 DAP	42 DAP	56 DAP	70 DAP
2003								
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
S.E.	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

Ah, alternate hill; Ar, alternate row; DAP, days after planting.
Within column for a given experiment, means followed by the same letter are not significantly different at $P<0.05$ (t-test).

The area-time-equivalent-ratio was calculated according to Hiebsch (1978), modified by Mutsaers *et al.* (1993), as follows:

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

where t_a and t_b are the growth period in days of crops a and b, respectively, in the monocrop 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), in order 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, the net production of the intercrop was compared with that of the monocrop. This requires calculating a 'replacement value of the intercrop' (RVI) according to Vandermeer (1989) as follows:

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

where I_m and I_a are the yields of maize and the associated crop (a), respectively, in intercrop 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 indicate that the intercrop is advantageous compared to the monocrop with insecticide use. The following prices were taken for calculating the RVI: maize = US\$ 0.1852 kg^{-1}, cassava = US\$ 0.0926 kg^{-1} fresh roots; cowpea = US\$ 0.7407 kg^{-1}, soybean = US\$ 0.5556 kg^{-1} and carbofuran = US\$ 4.6296 kg^{-1}, with US\$ 1 = 540 Franc CFA, the local currency in Cameroon.

Results

Abundance of borers in the different cropping patterns

During the long rainy season in 2002, colonization of plants by stem borer larvae started early (i.e. 28 DAP) on monocropped maize with 0.15 larvae per plant, when no larvae were 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 2). By contrast, larval densities decreased significantly with days after planting 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 in 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 2). 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

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Table 3. 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	

Ah, alternate hill; Ar, alternate row; IP, infested plot; TP, insecticide-treated plot. Others consisted of *Mussidia nigrivenella*, *Eldana saccharina*, *Cryptophlebia leucotreta* and *Sesamia calamistis*. 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).

ranged between 95.5–96.4% and 98.5–98.8 at 42 and 63 DAP, respectively.

Five borer species were found at harvest. *Busseola 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 3). Densities of the other species did not significantly vary among treatments both in the insecticide-treated and untreated plots (table 3). But, *B. fusca* larval densities were 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 3). 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 yield losses

During the long and short rainy season in 2002 and during the short rainy season in 2003, maize grain yields in insecticide-treated plots were 38.6–54.7% higher in monocrops than in intercrops (table 4). Yield differences between monocrops and intercrops were lower in the infested plots, with maize yields being 11.9–40.2% higher in the monocrop than in intercrops, during the long and short rainy season of 2002 and during the short rainy season of 2003 (table 4). The maize grain yields did not vary significantly among mixed cropping treatments during the long rainy season of 2003 (table 4). Maize yields were 45–51% 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). 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).

Relationships between maize yield, plant growth and damage variables

Plant height at harvest was significantly and 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 between larval densities and damage variables. Of all borers encountered at harvest, only *B. fusca* was significantly and positively correlated with percentage of 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* (Y) and percentage of stem tunnelling (X) was highly significant during the earlier

Table 4. Maize grain yield (t ha^{-1}) under different borer infestation levels and grain yield losses 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				
	Grain yield		Yield loss (%)	% Mono-intercrop		Grain yield		Yield loss (%)	% Mono-intercrop	
	IP	TP		IP	TP	IP	TP		IP	TP
2002										
Maize-mono	1.97	3.88	49.2	–	–	2.10	4.15	49.4	–	–
Maize–cassava/Ah	1.63	2.15	24.2	17.3	44.6	1.85	2.55	27.5	11.9	38.6
Maize–cassava/Ar	1.51	1.91	20.9	23.4	50.8	1.65	2.19	24.7	21.4	47.2
Maize–cowpea/Ah	1.30	1.87	30.5	34.0	51.8	1.45	1.88	22.9	31.0	54.7
Maize–cowpea/Ar	1.39	1.91	27.2	29.4	50.8	1.40	1.91	26.7	33.3	54.0
Maize–soybean/Ah	1.47	1.92	23.4	25.4	50.5	1.49	1.95	23.6	29.0	53.0
Maize–soybean/Ar	1.44	1.99	27.6	26.9	48.7	1.53	2.12	27.8	27.1	48.9
LSD	0.28					0.29				
d.f.	28					42				
2003										
Maize-mono	4.64	4.97	6.6	–	–	1.94	2.83	31.4	–	–
Maize–cassava/Ah	2.57	2.68	4.1	44.6	46.1	1.38	1.58	12.7	28.9	44.2
Maize–cassava/Ar	2.41	2.52	4.4	48.1	49.3	1.31	1.53	14.4	32.5	45.9
Maize–cowpea/Ah	2.44	2.59	5.8	47.4	47.9	1.17	1.31	10.7	39.7	53.7
Maize–cowpea/Ar	2.39	2.44	2.0	48.5	50.9	1.22	1.37	10.9	37.1	51.6
Maize–soybean/Ah	2.51	2.65	5.3	45.9	46.7	1.16	1.32	12.1	40.2	53.4
Maize–soybean/Ar	2.43	2.51	3.2	47.6	49.5	1.25	1.44	13.2	35.6	49.1
LSD	0.25					0.10				
d.f.	42					28				

Ah, alternate hill; Ar, alternate row; IP, infested plot; TP, insecticide-treated plot. LSD = least significant difference.

stages of plant growth but the r^2 decreased with age of the plant: 56 DAP (Y = −0.075 + 2.689*X, with $r^2 = 0.88$, $P < 0.0001$), 70 DAP (Y = 1.920 + 2.948*X, with $r^2 = 0.48$, $P < 0.0001$), at harvest (Y = 6.380 + 6.023*X, with $r^2 = 0.35$, $P < 0.0001$), across days after planting (Y = 4.128 + 2.753*X, with $r^2 = 0.31$, $P < 0.001$). The regression of percentage stem tunnelled versus grain weight showed that 1% increase in stem tunnelling lowered 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.

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 and 42–49 days after planting were significantly negatively related to yield: 28–35 DAP (the partial regression coefficient b = −32.88, F = 42.92, $P < 0.001$), 42–49 DAP (b = −34.22, F = 59.51, $P < 0.001$).

The percentage of stem tunnelled, internodes bored and cobs damaged did not significantly vary among treatments in the insecticide-treated plots (table 5). In insecticide-free plots, percentage of stem tunnelled 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 5). No differences between treatments 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 during 2002 and 2003 (table 5), while % cob 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 5). No differences were found during the other seasons (table 5).

Yield of associated crops and land-use efficiency

Cassava

The dry matter yield of cassava roots did not vary significantly among treatments planted during the long rainy seasons, and was on an average 3.75 and 4.28 t ha^{-1} during 2002 and 2003, respectively (table 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 t ha^{-1} in maize–cassava intercrops during the short rainy season of 2002.

Legumes

Compared to monocrops, legume yields in intercrops were significantly lower by 0.27–0.38 t ha^{-1} for cowpea and by 0.44–0.67 t ha^{-1} for soybean in both experiments in 2002 and 2003 (table 6). When planted in alternate rows, yield of cowpea and soybean were 0.15 and 0.17 t ha^{-1}, respectively higher than those planted in alternate hills during the long rainy season of 2002 (table 6). The same result was found in the long rainy season of 2003, albeit with lower yield differences of 0.08 and 0.11 t 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 t ha^{-1} more than those grown in alternate hills (table 6).

Land-use efficiency

Land-equivalent ratios (LER) and area-time equivalent ratios (ATER) for maize–cassava were consistently >1.0 in all seasons and for both planting patterns (table 7). They

Table 5. Least square means of stem tunnelling (%), internodes bored (%) and cobs damaged (%) 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	

Ah, alternate hill; Ar, alternate row; 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).

Table 6. Average dry matter yield ($t\,ha^{-1}$) of cassava roots and grain legumes grown as monocrop or intercrops with maize in alternate hills and alternate rows, 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

Ah, alternate hill; Ar, alternate row.
Yield data of the infested (IP) plots; LSD = least significant difference ($P < 0.05$).

Table 7. Land-equivalent-ratio, area-time-equivalent-ratio and 'replacement value of the intercrop' of maize–cassava, maize–cowpea and maize–soybean intercrops, planted in alternate hills or alternate rows, during the long and short rainy season of 2002 and 2003.

Treatments	Growing season													
	Long rainy season							Short rainy season						
	LER		ATER		Average		RVI	LER		ATER		Average		RVI
	IP	TP	IP	TP	IP	TP		IP	TP	IP	TP	IP	TP	
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

Ah, alternate hill; Ar, alternate row; ATER, area-time-equivalent ratio; IP, infested plot; LER, land-equivalent-ratio; RVI, replacement value of the intercrop; TP, insecticide-treated plot.
Average = (LER + ATER)/2.

were considerably higher than those for maize–cowpea and maize–soybean in all seasons. The average land-equivalent-ratio and area-time-equivalent-ratio for both maize-grain legume intercrops was >1.0 during 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 land-equivalent-ratio and area-time-equivalent-ratio were slightly >1.0 for alternate row planting of maize–cowpea and maize–soybean, but was about 1.0 for alternate hill planting of both intercrops. The land-equivalent-ratio and area-time-equivalent-ratio values of infested plots (IP) were consistently higher than those for plots treated with insecticide (TP) (table 7).

The 'replacement value 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 for maize–cassava were about twice as high as those for the maize–cowpea or maize–soybean treatments.

Discussion

Busseola fusca diapauses as a larva 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 & Schulthess, 2002). In 2002, rains started earlier than in 2003 and peaked in April and October compared to July and October in 2003 (Chabi-Olaye *et al*., 2005a). Thus, very likely in 2002, *B. fusca* terminated diapause earlier resulting in a faster build-up of pest populations compared to 2003, thereby causing higher yield losses during the first season of 2002. Likewise, severity of borer damage, as evidenced by the % stem tunnelled 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 & Way, 1970; Adesiyun, 1979) or to different rates of multiplication in the crop as well as mortality rates (Way & 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* by Chabi-Olaye *et al* (2005a). 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 neighbouring 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 were 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

https://doi.org/10.1079/BER2005373 Published online by Cambridge University Press

shows that the proportion of stem tunnelling is a far more reliable indicator of yield loss than numbers of pests. This was confirmed by several authors for various African stem borer species (Bosque-Pérez & 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 and negatively related to the number of larvae found during the vegetative stage of plant growth. Thus, larval counts made during the vegetative growth of the maize plants were a reliable predictor for the extent of yield losses at harvest.

Our findings showed that the land-equivalent-ratio was higher than the area-time-equivalent-ratio in all the cropping patterns. According to Mason *et al*. (1986), land-time-equivalent-ratios overestimate and area-time-equivalent-ratios underestimate the land use efficiency. Thus, they suggested that land-equivalent-ratio and area-time-equivalent-ratio should be averaged to provide a more consistent estimate of land use efficiency. In the present study, maize–cassava intercrops showed a 46–77% greater land use efficiency compared to monocrops, across all seasons. Cassava is one of the most important sources for carbohydrates in sub-Sahara Africa (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, 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 between 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 pure maize stands treated with carbofuran, as demonstrated by highly positive 'replacement value for intercrops' (RVI) (table 7). However, according to Mutsaers *et al*. (1993), high maize yields in maize cassava intercrops of above $3.5\,\mathrm{t\,ha^{-1}}$, 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 the monocrop. This was also the trend in these trials, where higher crop yields in the long rainy season of 2003 had much lower 'replacement value for intercrops' (RVI) than lower crop yields in the short rainy season of 2003. At present it is not possible to determine at what yield and price levels of maize and cassava and at what level of *B. fusca* infestation, an intercrop is no longer preferable to a monocrop. This would require further experiments.

Intercropping maize with cowpea and soybean resulted in lower land-equivalent-ratio and 'replacement value for intercrops' (RVI) than with cassava. In all four seasons, both grain legumes had a similar effect on stem borer 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 monocrop resulted in 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 6). In contrast to cassava, both maize and grain legumes have a phasic growth pattern and take 3–4 months to reach 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, maize, a C4 plant is more competitive than the C3 plants cowpea and soybean (Ofori & Stern, 1987) and, in general, a high land-equivalent-ratio is obtained when the dominated species produces a high partial land-equivalent-ratio, while the other component has a partial land-equivalent-ratio of close to 1.0 (Fukai & Trenbath, 1993). Thus, Härdter *et al*. (1991) increased the land-equivalent-ratio and area-time-equivalent-ratio of a maize–cowpea intercrop considerably through fertilizer application in low input systems in northern Ghana. However, the opposite was found by Ofori & Stern (1986) in highly intensive systems in Western Australia.

Conclusions

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 offered the additional advantage that land productivity was higher than with monocrop. The maize–cassava crop was the most efficient in terms of land use and the most productive vis-à-vis pure maize stand with insecticide application. At medium intensity or cropping this system is thus recommendable to land-constrained poor farmers who do not use external inputs such as fertilizer.

Acknowledgement

This study was financed by a grant from the German Research Council (DFG).

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(Accepted 20 April 2005)