J. Appl. Entomol. **131(1)**, 40–49 (2007) doi: 10.1111/j.1439-0418.2006.01116.x

© 2007 ICIPE
Journal compilation © 2007 Blackwell Verlag, Berlin

The role of intercropping different cereal species in controlling lepidopteran stemborers on maize in Kenya

J. M. Songa[1], N. Jiang[2], F. Schulthess[2] and C. Omwega[2]
[1]Kenya Agricultural Research Institute, Biotechnology Centre, Nairobi, Kenya; [2]International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya

Ms. received: September 20, 2006; accepted: October 12, 2006

Abstract: The effects of mixed cropping systems containing maize, sorghum, millet and beans on infestations of cereals by lepidopteran stemborers and on associated parasitoids, as well as on yields and land equivalent ratios (LER) were assessed during four consecutive rainy seasons at two sites in the semi-arid eastern region of Kenya. Systems containing the non-host bean were more efficient in reducing pest densities than those with millet or sorghum only. Higher parasitism in diversified systems compared to monocrops was due to density-dependent effects rather than superior suitability of such systems to parasitoids. The maize–bean system, which had the highest proportion of bean plants, had LERs > 1.65 while most other systems had LERs < 1. It is concluded that mixed cropping with several cereal species has little advantages in terms of yield loss abatement due to stemborers and land use efficiency. However, including the drought-tolerant crops such as sorghum and millet in the system stabilizes food security in drought-prone areas such as eastern Kenya.

Key words: intercropping system, maize, parasitism, semi-arid, stemborer, yield

1 Introduction

Maize is the main staple for the majority of households in Kenya, contributing to about 12% of the rural households' income (Argwings-Kodeck et al. 1998). Yields are around 1.4 ton/ha, which is only 30% of the world average (FAO 2000). In semi-arid and arid areas, which comprise 80% of Kenya's land area and 50% of the country's arable land (Jaetzold and Schmidt 1983), yields average 0.5 ton/ha only. One of the main biotic constraints to cereal production in sub-Saharan Africa is a complex of lepidopteran stemborers with losses in outbreak areas ranging between 10% and 60% (Bosque-Pérez and Mareck 1991; Chabi-Olaye et al. 2005a,b; Endrody-Younga 1968; van Rensburg 1988; Gounou et al. 1994; Mgoo et al. 2006). In the eastern region of Kenya, the most destructive species is the invasive crambid *Chilo partellus* (Swinhoe) (Zhou et al. 2001b; Songa et al. 2002).

In 1993, the exotic braconid larval parasitoid *Cotesia flavipes* (Cameron) was released at the Kenyan Coast for control of *C. partellus* (Omwega et al. 1995; Overholt et al. 1997). By 1998, it had reduced *C. partellus* density by 57% and increased maize yields by 10–15% (Zhou et al. 2001a). Recent surveys showed that parasitism is still increasing and pest populations are decreasing (Jiang et al. 2006). It has since then been released in major maize-growing areas in eastern, central and western Kenya (Songa et al. 2001). Besides biological control, major emphasis has been given in recent years to the development of habitat management techniques such as crop rotation, soil fertility measures and mixed cropping. Many studies in tropical as well as temperate zones reported decreased pest densities in diversified cropping systems (Altieri and Letourneau 1982; Risch et al. 1983; Andow 1991; Thies and Tscharntke 1999; Kruess and Tscharntke 2000). In Africa, small-scale farmers traditionally practice intercropping in order to obtain a greater total land productivity, expressed here as the land equivalent ratio (LER), and as an insurance against the failure or unpredictable market value of a single crop (Vandermeer 1989). Recent studies in western Africa showed that intercropping maize with non-host plants such as legumes or cassava, which is common in the region, reduced borer infestations by up to 80% (Schulthess et al. 2004; Chabi-Olaye et al. 2005b). In addition, as pointed out by Cardinale et al. (2003), changes in pest densities could also influence diversity and the performance of natural enemies of pests.

In contrast to western Africa, intercropping of several cereal species, which are hosts of stemborers, and the non-host beans are commonly practised in the semi-arid and arid areas of Kenya. In this study, the land use efficiency, pest and natural enemy densities in mono crops and in mixtures of maize, millet, sorghum and beans planted in different arrangements was assessed at two sites and during four consecutive cropping seasons in eastern Kenya.

2 Materials and Methods

2.1 Study sites

The study was conducted on field stations of the Kenya Agricultural Research Institute (KARI) at Katumani (1 °35′S, 37 °14′E, 1 575 m a.s.l.) and Kiboko (2 °30′S, 37 °50′E, 960 m. a.s.l.), in the semi-arid areas of eastern Kenya, during four consecutive cropping seasons, namely the short rains of 2003 and 2004, and the long rains of 2004 and 2005. The rainfall pattern in both sites is bi-modal averaging, respectively, 700 and 600 mm at Katumani and Kiboko (Anon 1984; Stewart and Faught 1984). Annual mean temperatures are around 20 °C at both sites. The long rainy season lasts from March to May and the short one from October to November. However, in recent years, rainfall has become highly unreliable and it is not unusual to receive higher precipitation in the short than in long rainy season.

Eight treatments were planted in a randomized complete block design and replicated three times. They represent the degree of system diversity encountered in farmers' fields. Plots measured 7.2 × 6 m separated by 5 m. Four crop species were used, i.e., maize, *Zea mays* L. (var Katumani Composite B), pearl millet, *Pennisetum glaucum* (L.) (var. Katumani Peal millet -1), sorghum, *Sorghum bicolor* L. (var. KARI Mtama-1) and bean, *Phaseolus vulgaris* L. (var. Rose Coco). Maize was monocropped or inter-cropped with bean, millet, with or without sorghum as a border, and, in accordance with farmers' practices, all crops were planted at the same time. There were three mono crops: (i) maize mono crop, (ii) millet mono crop and (iii) sorghum mono crop. In the mono crops, two seeds of maize were sown per hill at a spacing of 30 cm within and 90 cm between rows and thinned to one plant at 14 days after emergence. Millet and sorghum mono crops were planted at a spacing of 60 cm between and 25 cm within rows, and beans at 60 cm between and 10 cm within rows. There were five intercropping systems: (1) maize planted in alternating rows with bean (maize–bean), where the distance between beans and maize within a row was respectively, 10 and 30 cm, and the distance between rows was 60 cm; (2) maize mono crop with three rows of sorghum around the 7.2 × 6 m plot (maize–sorghum); (3) maize inter-planted in the same row with millet (maize–millet) with 30 cm between maize and millet plant; (4) maize inter-planted with millet as above, and in alternating rows of bean, maize, bean and again maize with millet (maize–millet–bean); distance between maize and millet within a row was 30 cm, and that between rows was 60 cm; (5) the same as (4) but with a sorghum border (maize–millet–bean–sorghum), where five sorghum rows were planted around each plot. For each crop species and cropping system the plant density per hectare is shown in table 1. Densities commonly found in farmers' fields were used.

2.2 Data collection

Among the four crops, bean was the earliest maturing, followed by millet and maize, while sorghum was the latest. Sampling of all crops was when maize was in hard dough stage (Oloo 1989). Sixty whole plants per plot were randomly sampled in mono crops while in intercrops, 30 plants from maize and each companion crop species, with the exception of the non-host bean, were sampled.

Table 1. *Plant density/ha of the different crops in the mono and intercrops*

	Maize	Bean	Millet	Sorghum
Maize mono	37 000	–	–	–
Millet mono	–	–	67 000	–
Sorghum mono	–	–	–	67 000
Bean mono	–	170 000	–	–
Maize–sorghum	37 000	–	–	67 000
Maize–bean	28 000	83 000	–	–
Maize–millet	19 000	–	19 000	–
Maize–millet–bean	14 000	83 000	7000	–
Maize–millet–bean–sorghum	14 000	83 000	7000	67 000

Data were taken on the following parameters: the number of stemborers and their life stages per stemborer species; plant height, stem diameter, plant damage variables, i.e. the number of internodes and internodes bored, stem tunnel length were obtained from maize. Each stemborer larvae recovered was reared individually on artificial diet in glass vials plugged with cotton wool to await possible emergence of adult moths or parasitoids. The parasitoids were identified by the ICIPE's Biosystematics Unit, where voucher specimens are kept in a reference collection. At harvest, yields of the individual crop species were taken from the centre 6.6 m × 3.6 m area of each plot. Yield of sorghum as a border was ignored because the amount was small.

2.3 Data analysis

Mixed model (PROC MIXED) (SAS 2000) was used to estimate the contribution of fixed and random effects to the variance of the dependent variables *yij*:

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

where μ is the general mean, α_i is the fixed effect of *i*th intercropping system, β_j is the block replication of each intercropping system, the random effect, and ε_{ij} is the within-block error. Mixed model uses a restricted maximum likelihood (REML) approach for unbalanced data; it does not directly compute or display sums of squares for this analysis. As there were only two sites selected, the site can be treated as fixed effects (Piepho et al. 2004) and the season as repeated effects. The mean comparison of fixed effect of cropping systems was made by least square means (LSMEANS). However, when the data are unbalanced, the standard error of a difference (SED) is not constant among comparisons, and hence there is no common critical difference. Therefore, the effects on the stemborer density, species composition, crop growth and damage variables were analysed used the method developed by Piepho (2004). In our study, the intercropping system was coded CROP, site is LOC, and season by S. Difference between sites are usually assumed to be large, thus, a cropping system-by-site-interaction (CROP × LOC) must be postulated. Difference between seasons-by-sites (LOC × S) and by-cropping system CROP × S are also included. By using ESTIMATE from PROC MIXED, the effect of specific associated crops on stemborer density and maize growth or damage parameters was compared for a specific season and site. Grain weight was compared by ANOVA (PROC GLM). The percentage of tunnelling length was calculated by dividing the tunnel length by the plant height and then multiplying by 100; the percentage of bored internodes was calculated by dividing the number of bored internodes by the total number of internodes per plant and then multiplying by 100. Insect counts were log($x + 1$) transformed and the percentage data were arcsine square root-transformed before analysis.

The LER of maize intercropping systems was used to measure the efficiency of each cropping mixture:

$$\mathrm{LER} = \frac{I_\mathrm{m}}{M_\mathrm{m}} + \frac{I_\mathrm{a}}{M_\mathrm{a}} + \frac{I_\mathrm{b}}{M_\mathrm{b}},$$

where I_m, I_a and I_b are the yields of maize and associated crops of 'a' and 'b', respectively, in intercropping, M_m, M_a and M_b stand for the yields of maize and other associated crops of 'a' and 'b', respectively, in the mono crop. If LER is > 1, the intercrop is more efficient in terms of land use and if it is < 1 the monoculture is more efficient.

Secondly, the net production of maize mono and intercropped crops were compared using a 'replacement value of the intercrop' (RVI) (Vandermeer 1989) as follows:

$$\mathrm{RVI} = \frac{p_\mathrm{m} I_\mathrm{m} + p_\mathrm{a} I_\mathrm{a} + p_\mathrm{b} I_\mathrm{b}}{p_\mathrm{m} M_\mathrm{m}}$$

where the prices of maize (p_m) and the companion crops (p_a, p_b) are included. RVI > 1.0 indicates that the intercrop is advantageous compared with the mono crop. The following market prices collected in eastern Kenya were used: maize = 16Ksh/kg, millet = 29Ksh/kg; sorghum = 22Ksh/kg, and bean = 39Ksh/kg, with 1USD = 72 Ksh (*The Standard Newspaper*, 21 February 2006).

3 Results

3.1 Stemborer density and species composition

Borer densities varied significantly with season and location but not cropping system (table 2). Season (S) × location (LOC) and S × LOC × cropping system (CROP) interactions were significant while S × CROP was not. Plant damage and growth variables followed a similar trend, except that stem tunnelling and plant growth variables varied significantly with cropping system and their S × CROP interactions were significant. As percent tunnelling and internode damages followed a very similar trend and the significance of differences in tunnel length was higher than that of internodes damaged, only the result of the former will be presented.

When pooled across seasons, borer density on maize at Katumani was highest on maize mono and maize–millet and in Kiboko in all cropping systems except maize–millet–bean and maize–millet–bean–sorghum. At Katumani, percent tunnel length in maize stems was significantly lowest in the maize–bean and maize–millet–bean systems and at Kiboko were highest in the maize mono and maize–millet and similar in the other cropping systems (table 3). There were no clear trends for millet. Borer densities and tunnel length were higher in Kiboko than in Katumani in all cropping systems and both cereal crops, and they were lower on millet than on maize (table 3). For sorghum, they were only assessed in the monocrops, and both pest densities and plant damage were much higher on sorghum than on maize and millet.

Three stemborer species were collected at both sites: *C. partellus*, *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae), and *Busseola fusca* Fuller (Lep.: Noctuidae). *Chilo partellus* was the dominant species while *B. fusca* was scarce, only found during the last trial. At Katumani, the relative importance of *C. partellus* on maize and millet did not vary with cropping system, while at Kiboko, the highest percentage on maize was found on maize–bean and the lowest in the systems containing millet (table 3). On average, it accounted for 85.4%, 74.6% and 55.6% of all species on sorghum, maize and millet respectively.

3.2 Effect of the companion crops, sorghum, bean and millet on damage symptoms and borer density on maize

In general, the cropping system had a limited effect on stemborer density and plant damage irrespective of companion crop(s) (table 4). Significant differences were found in, respectively, 25.0%, 31.3% and 28.2% of all cases, where sorghum, bean or millet was included in the system. When maize was intercropped with sorghum, differences in borer densities and plant damage, if significant, were higher on mono than intercropped maize. Maize–millet–bean yielded lower values than the same system with sorghum as border. Monocropped maize had also higher borer densities and percent tunnelling than maize–bean, and maize–millet more than maize–millet–bean. In maize systems with or without millet where compared, cases at Katumani millet lowered borer densities and percent tunnel length while at Kikobo, it was the opposite (table 4).

Table 2. *The estimation of effects of season and cropping systems on the stemborer density and* Chilo partellus *species composition, as well as plant growth and damage parameters per plant using mixed model, during the short rains of 2003 and 2004 and the long rains of 2004 and 2005 at Katumani and Kiboko, in eastern Kenya*

	Borer density		% tunnel length		% bored internodes		Height (cm/plant)		Diameter (cm/plant)		*C. partellus* (%)	
	F	P	*F*	P	*F*	P	*F*	P	*F*	P	*F*	P
S	132.3	0.0001	733.5	0.0001	458.5	0.0001	1103.4	0.0001	7.5	0.006	81.8	0.0001
LOC	98.0	0.0001	415.8	0.0001	488.4	0.0001	500.9	0.0001	86.8	0.0001	5.0	0.025
CROP	1.2	0.298	2.63	0.022	1.68	0.136	12.0	0.0001	4.5	0.0004	1.5	0.171
LOC × CROP	4.7	0.0003	1.33	0.247	2.16	0.056	10.2	0.0001	10.1	0.0001	2.4	0.036
S × CROP	0.9	0.479	1.54	0.173	1.54	0.175	14.3	0.0001	2.3	0.042	1.7	0.122
S × LOC	37.3	0.0001	113.6	0.0001	144.9	0.0001	309.8	0.0001	0.26	0.611	20.5	0.0001
S × LOC × CROP	3.4	0.004	2.00	0.075	2.89	0.013	11.0	0.0001	8.7	0.0001	5.0	0.0002

S, season; LOC, location; CROP, cropping system.

Table 3. *Comparison across season means of stemborer densities, plant damage and the relative importance (%) of* Chilo partellus *on maize, millet and sorghum in different cropping systems at Katumani and Kiboko, in eastern Kenya*

	Maize		Millet		Sorghum	
	Katumani	Kiboko	Katumani	Kiboko	Katumani	Kiboko
Borer density (/plant)						
Maize mono	0.20 ± 0.02 aB	0.49 ± 0.04 aA	–	–	–	–
Millet mono	–	–	0.04 ± 0.01 bB	0.18 ± 0.02 abA	–	–
Sorghum mono	–	–	–	–	0.97 ± 0.07	2.5 ± 0.09
Maize–sorghum	0.11 ± 0.01 bB	0.44 ± 0.05 aA	–	–	–	–
Maize–bean	0.14 ± 0.02 bB	0.41 ± 0.04 aA	–	–	–	–
Maize–millet	0.21 ± 0.03 aB	0.38 ± 0.05 aA	0.06 ± 0.02 abB	0.18 ± 0.02 aA	–	–
Maize–millet–bean	0.16 ± 0.03 bB	0.33 ± 0.05 bA	0.05 ± 0.01 bB	0.11 ± 0.02 bA	–	–
Maize–millet–bean–sorghum	0.15 ± 0.03 bB	0.29 ± 0.05 bA	0.11 ± 0.03 aB	0.16 ± 0.02 abA	–	–
% tunnel length						
Maize mono	3.7 ± 0.3 abB	8.9 ± 0.42 aA	–	–	–	–
Millet mono	–		1.1 ± 0.2 bB	4.3 ± 0.2 aA	–	–
Sorghum mono	–		–	–	12.4 ± 0.6	31.3 ± 0.8
Maize–sorghum	3.9 ± 0.7 abB	7.6 ± 0.4 bA	–	–		
Maize–bean	3.0 ± 0.3 bB	7.3 ± 0.4 bA	–	–	–	–
Maize–millet	4.0 ± 0.4 aB	9.5 ± 0.6 aA	1.3 ± 0.2 abB	4.8 ± 0.5 abA	–	–
Maize–millet–bean	2.9 ± 0.4 bB	6.5 ± 0.5 bA	1.4 ± 0.3 abB	4.4 ± 0.4 abA	–	–
Maize–millet–bean–sorghum	4.1 ± 0.5 aB	6.7 ± 0.5 bA	2.3 ± 0.4 aB	3.6 ± 0.3 bA	–	–
Chilo partellus (%)						
Maize mono	72.4 ± 4.6 aA	74.7 ± 3.1 bA	–	–	–	–
Millet mono	–	–	40.4 ± 9.6 aA	42.7 ± 4.7 bA	–	–
Sorghum mono	–	–	–	–	86.8 ± 1.8	84.0 ± 1.3
Maize–sorghum	81.2 ± 4.7 aA	80.2 ± 3.0 abA	–	–	–	–
Maize–bean	85.3 ± 4.5 aA	87.4 ± 2.6 aA	–	–	–	–
Maize–millet	74.9 ± 5.7 aA	48.5 ± 5.4 cB	47.4 ± 11.1 aA	66.4 ± 6.5 aA	–	–
Maize–millet–bean	73.2 ± 7.3 aA	62.8 ± 5.6 cB	62.5 ± 11.1 aA	59.5 ± 9.2 aA	–	–
Maize–millet–bean–sorghum	78.8 ± 6.4 aA	60.3 ± 5.8 cB	70.4 ± 8.9 aA	55.3 ± 7.1 abA	–	–

Means within column followed by the same lower-case letter and within row followed by the same upper-case letter are not significantly different at P ≤ 0.05 (Student–Newman–Keuls test).

3.3 Stemborer parasitism

The parasitoid species recovered were dominated by larval parasitoids, e.g. *Cotesia flavipes*, *Cotesia*, *sesamiae* (Hym., Braconidae), *Sturmiopsis parasitica* (Curran) (Diptera: Tachinidae), *Chelonus curvimaculatus* Cameron (Hymenoptera: Braconidae) and *Stenobracon rufus* (Szépligeti) (Braconidae); pupal parasitoids included *Dentichasmias busseolae* Heinrich (Hym., Ichneumonidae) and *Pediobius furvus* (Hym., Eulophidae). The hyperparasitoids *Aphanogmus fijiensis* (Ferrière) (Ceraphronidae), which attacks *Cotesia* spp., and *Eurytoma braconidis* Ferrière (Eurytomidae), which attacks *Stenobracon* sp. and *Habrobracon brevicornis*, were also recovered. The range and parasitism of stemborers was generally higher in Kiboko than in Katumani ($\chi^2 = 27.6$, $P = 0.0001$). Except for *C. flavipes* parasitism was low. Thus, only *C. flavipes* and all pupal parasitoids pooled were included in the analyses. At Katumani, parasitoids were mainly recovered from maize and sorghum mono cropping systems during the first and second trial season. At Kiboko, *C. flavipes* were recovered from *C. partellus* from cropping systems except from monocropped millet during the first season. Parasitism, by both *Cotesia* sp. and pupal parasitoids, tended to be highest on millet and cropping systems with millet (table 5). Across all parasitoid species, cropping systems, locations and seasons, a negative relationship was found between parasitism (y) and borer numbers (x): $y = 39.5–8.0\ln(x)$, ($P < 0.0001, r^2 = 0.41$).

3.4 Crop yield and economic analysis

There were significant differences between cropping systems in grain yield of maize at both sites and the four seasons. There was a trend of two groupings, one with maize mono, maize–sorghum, maize–bean, and one containing maize–millet, maize–millet–bean and maize–millet–bean–sorghum, with higher yields for the former (table 6). As for millet, yields were highest in monocrops and similar in the other cropping systems, which had millet. Where significant, a similar trend was observed for beans. With the exception of maize yields in the maize–bean system, yields for each crop reflected the plant density in table 1.

Land equivalent ratio and RVI followed the same trend (table 7). For the maize–millet, maize–millet–bean and maize–millet–bean–sorghum systems the values were, with two exceptions, smaller than 1, and mostly below 0.6. The highest values were calculated for maize–bean, which were always considerably > 1, followed by maize-sorghum, which in 50% of the cases yielded values of > 1.

Table 4. *Effects of (a) sorghum border, (b) beans and (c) millet as companion crops on stemborer density, maize plant growth and damage parameters during four seasons in 2003–2005 at Katumani and Kiboko*

	Short rains, 2003		Long rains, 2004		Short rains, 2004		Long rains, 2005	
Katumani	*t*	P	*t*	P	*t*	P	*t*	P
(a)								
Maize mono vs. maize–sorghum								
Borer density	0.77	0.441	1.61	0.108	0.13	0.895	2.41	**0.016**
TL%	0.76	0.446	0.72	0.474	−0.23	0.819	0.74	0.460
Kiboko								
Borer density	0.13	0.890	2.58	**0.010**	−0.09	0.930	0.35	0.730
TL%	0.66	0.512	3.13	**0.002**	0.29	0.769	2.32	**0.021**
Maize–millet–bean vs. maize–millet–bean–sorghum								
Borer density	0.91	0.363	1.05	0.295	0.75	0.453	−2.29	**0.022**
TL%	−2.22	**0.027**	0.17	0.865	−1.00	0.316	0.86	0.392
Kiboko								
Borer density	−1.18	0.236	1.29	0.196	−0.49	0.627	−0.48	0.632
TL%	−1.98	**0.048**	0.46	0.647	0.30	0.765	1.36	0.174
(b)								
Maize mono vs. maize–bean								
Borer density	−0.25	0.441	1.63	0.108	0.21	0.894	2.95	**0.016**
TL%	−0.36	0.720	1.96	0.051	0.30	0.768	2.43	**0.015**
Kiboko								
Borer density	−0.79	0.430	3.93	**0.0001**	0.86	0.388	−0.17	0.863
TL%	1.69	0.091	2.63	**0.009**	2.17	**0.030**	0.92	0.356
Maize–millet vs. maize–millet–bean								
Borer density	2.73	**0.006**	0.92	0.358	0.81	0.4178	−0.76	0.447
TL%	2.95	**0.003**	1.54	0.123	0.31	0.7570	−0.20	0.838
Kiboko								
Borer density	−0.01	0.988	0.29	0.771	0.23	0.819	1.94	0.052
TL%	1.64	0.102	2.55	**0.011**	2.91	**0.004**	2.15	**0.032**
(c)								
Maize mono vs. maize–millet								
Borer density	−3.44	**0.0006**	0.96	0.335	−0.55	0.584	1.06	0.288
TL%	−3.29	**0.001**	1.18	0.238	−0.17	0.867	−0.29	0.770
Kiboko								
Borer density	2.20	**0.028**	2.70	**0.007**	−0.34	0.736	−1.51	0.132
TL%	1.61	0.107	−0.95	0.343	−2.66	**0.008**	0.16	0.875
Maize–bean vs. maize–millet–bean								
Borer density	−0.07	0.941	0.69	0.489	0.22	0.828	−2.22	**0.026**
TL%	0.40	0.686	1.37	0.172	−0.05	0.959	−2.51	**0.012**
Kiboko								
Borer density	2.82	**0.005**	−0.18	0.859	−0.78	0.437	0.87	0.382
TL%	2.12	**0.034**	−0.15	0.881	−1.06	0.289	1.88	0.060

A negative *t*-value indicates that when comparing two treatments the first treatment yielded lower values than the second. TL%, percent tunnel length.

Table 5. *Mean across seasons and location parasitism of stemborers (%) in the different cropping systems in eastern Kenya (in parentheses the rank by Wilcoxon scores method)*

Cropping system	Cocoon	*Cotesia flavipes*	*Cotesia sesamiae*	Pupal parasitism
Maize mono	6.8 ± 5.7 (22)	6.9 ± 1.2 (25)	–	15.1 ± 7.1 (12)
Sorghum mono	7.4 ± 2.1 (22)	2.8 ± 0.4 (10)	–	1.6 ± N/A (1)
Millet mono	11.8 ± N/A (15)	11.8 ± N/A (11)	–	–
Maize–bean/Ar	2.8 ± N/A (10)	2.2 ± N/A (39)	–	–
Maize–millet	14.3 ± 6.1 (47)	8.1 ± 2.1 (58)	–	11.3 ± 5.4 (8)
Maize–millet–bean/Ar	–	18.9 ± 6.1 (27)	–	100.0 ± N/A (8)
Maize–sorghum/B	2.4 ± 0.6 (28)	3.1 ± 0.4 (29)	–	–
Maize–millet–bean/Ar–sorghum/B	18.9 ± 10.5 (46)	18.8 ± 11.1 (29)	6.7 ± N/A	50.0 ± N/A (7)
χ^2	14.23	12.08	–	5.33
P	0.027	0.034	–	0.255

4 Discussion

Vandermeer (1989) listed three possible mechanisms responsible for reduced pest infestation in mixed cropping systems: (a) the 'disruptive-crop hypothesis', in which a second non-host plant species disrupts the ability of the pest to find its proper host plant species; this can be due to both reduced chemical and visual cues and stimuli (Finch and Collier 2000); (b) the 'trap crop hypothesis' in which a second non-suitable host

Table 6. *Yields of maize and companion crops (1000 kg/ha) in different cropping systems during four seasons from 2003 to 2005, at Katumani and Kiboko in eastern Kenya*

	Katumani				Kiboko			
	Short rains, 2003	Long rains, 2004	Short rains, 2004	Long rains, 2005	Short rains, 2003	Long rains, 2004	Short rains, 2004	Long rains, 2005
Maize								
Maize mono	0.37 ± 0.11 ab	1.65 ± 0.03 ab	1.83 ± 0.22 b	2.68 ± 1.04 ab	2.30 ± 0.10 a	1.68 ± 0.54 ab	2.41 ± 0.78 bc	2.57 ± 0.42 b
Maize–sorghum	0.24 ± 0.11 ab	2.65 ± 0.43 a	1.67 ± 0.53 b	2.47 ± 0.09 ab	2.28 ± 0.28 a	2.85 ± 0.27 a	3.04 ± 0.61 ab	2.82 ± 0.08 b
Maize–bean	0.58 ± 0.25 a	2.49 ± 0.70 a	2.78 ± 0.25 a	3.80 ± 1.25 a	2.94 ± 0.28 a	2.75 ± 1.04 a	4.38 ± 0.40 a	3.97 ± 0.35 a
Maize–millet	0.00 ± 0.00 b	0.67 ± 0.11 b	0.98 ± 0.16 bc	1.35 ± 0.41 ab	0.89 ± 0.26 b	1.05 ± 0.06 ab	0.93 ± 0.18 c	1.10 ± 0.32 c
Maize–millet–bean	0.12 ± 0.05 ab	0.53 ± 0.12 b	0.58 ± 0.12 c	0.66 ± 0.21 b	0.66 ± 0.07 b	0.55 ± 0.05 b	0.61 ± 0.07 c	0.59 ± 0.08 c
Maize–millet–bean–sorghum	0.02 ± 0.02 b	0.41 ± 0.12 b	0.38 ± 0.02 c	0.55 ± 0.08 b	0.70 ± 0.04 b	0.48 ± 0.10 b	0.44 ± 0.07 c	0.86 ± 0.09c
F	3.25	8.6	11.2	3.41	25.4	4.6	10.0	25.4
P	0.04	0.001	0.0003	0.038	0.0001	0.014	0.0006	0.0001
Millet								
Millet mono	0.66 ± 0.38	0.52 ± 0.04 a	0.57 ± 0.15 a	1.69 ± 0.23 a	3.19 ± 1.00 a	1.70 ± 0.30 a	2.09 ± 0.27 a	2.05 ± 0.35 a
Maize–millet	0.04 ± 0.02	0.12 ± 0.004 b	0.16 ± 0.04 b	0.26 ± 0.04 b	0.22 ± 0.08 b	0.28 ± 0.04 b	0.28 ± 0.08 b	0.33 ± 0.13 b
Maize–millet–bean	0.02 ± 0.01	0.04 ± 0.006 c	0.04 ± 0.02 b	0.09 ± 0.01 b	0.09 ± 0.02 b	0.07 ± 0.02 b	0.11 ± 0.01 b	0.10 ± 0.01 b
Maize–millet–bean–sorghum	0.03 ± 0.01	0.03 ± 0.003 c	0.05 ± 0.01 b	0.12 ± 0.02 b	0.06 ± 0.03 b	0.09 ± 0.03 b	0.07 ± 0.01 b	0.13 ± 0.01 b
F	2.73	122.29	9.71	44.01	9.28	26.48	48.18	25.17
P	0.1137	0.0001	0.0048	0.0001	0.0055	0.0002	0.0001	0.0002
Sorghum								
Sorghum mono	1.00 ± 0.13	2.26 ± 0.49	1.48 ± 0.31	2.13 ± 0.44	2.33 ± 0.71	3.97 ± 0.35	4.31 ± 0.53	3.46 ± 0.41
Bean								
Bean mono	–	–	0.95 ± 0.07 a	0.76 ± 0.10 a	–	–	0.06 ± 0.02	0.26 ± 0.06
Maize–bean	0.04 ± 0.002	0.36 ± 0.04	0.36 ± 0.03 b	0.26 ± 0.04 b	0.02 ± 0.001 c	0.18 ± 0.07	0.06 ± 0.02	0.27 ± 0.06
Maize–millet–bean	0.04 ± 0.006	0.27 ± 0.03	0.19 ± 0.07 b	0.29 ± 0.04 b	0.18 ± 0.02 a	0.04 ± 0.01	0.03 ± 0.01	0.16 ± 0.03
Maize–millet–bean–sorghum	0.03 ± 0.006	0.24 ± 0.06	0.32 ± 0.04 b	0.13 ± 0.02 b	0.07 ± 0.008 b	0.04 ± 0.01	0.05 ± 0.02	0.20 ± 0.03
F	1.24	2.13	35.27	21.24	30.70	4.11	0.41	1.25
P	0.3552	0.2003	0.0001	0.0004	0.0007	0.0752	0.7527	0.3541

Means followed by the same lower-case letter in a column were not significantly different at $P \leq 0.05$ (Student–Newman–Keuls test).

Table 7. *Land equivalent ratio (LER) and replacement value of the intercrop (RVI) of different intercropped systems during four seasons from 2003 to 2005, at Katumani and Kiboko in eastern Kenya*

	Short rains, 2003		Long rains, 2004		Short rains, 2004		Long rains, 2005	
	LER	RVI	LER	RVI	LER	RVI	LER	RVI
Katumani								
Maize–sorghum	0.65	0.65	1.61	1.61	0.91	0.91	0.92	0.92
Maize–bean	–	–	–	–	1.73	1.99	1.76	1.65
Maize–millet	0.06	0.19	0.64	0.54	0.82	0.69	0.66	0.68
Maize–millet–bean	–	–	–	–	0.59	0.61	0.70	0.59
Maize–millet–bean–sorghum	0.13	0.40	0.59	0.63	0.63	0.68	0.45	0.40
Kiboko								
Maize–sorghum	0.99	0.99	1.10	1.10	1.26	1.26	1.10	1.10
Maize–bean	–	–	–	–	2.82	1.88	2.58	1.80
Maize–millet	0.46	0.56	0.59	0.62	0.52	0.59	0.59	0.66
Maize–millet–bean	–	–	–	–	0.81	0.37	0.89	0.45
Maize–millet–bean–sorghum	–	–	–	–	1.05	0.28	1.17	0.61

–, Yields of monocropped beans were not assessed.

plant species attracts the pest away from its primary host; (c) the ‘natural enemy hypothesis’ in which the intercropping situation attracts more predators and parasitoids than the monocrop thereby reducing pests on the primary host plant. The results of the present trials, which include mixtures of several cereal species and the exotic *C. partellus*, were not very consistent. In general, the systems containing the non-host bean were more efficient in reducing pest densities than those with millet or sorghum only, with the exception of the maize–sorghum system at Katumani, which had 55% lower borer density compared with the maize monocrop. Ampong-Nyarko et al. (1994) showed that when sorghum was mixed with cowpea or cassava, *C. partellus* laid about a third of their eggs on non-host crops. The eggs were able to hatch on cowpea but the number of neonate larvae that reached the sorghum host diminished with distance. Thus, for the invasive *C. partellus*, these non-host species acted as trap crops, which thereby formed a reproductive sink. As eggs were not counted in the present trials further experiments are required to determine whether bean plants acted as trap plants and/or disrupted host finding of the ovipositing moth or dispersing larvae. In a study by Adesiyun (1983), *B. fusca* was shown not to oviposit on pearl millet; this reduced larval infestation of sorghum when interplanted with millet. By contrast, both crops are acceptable and suitable hosts for the invasive *C. partellus*. In our trials, no difference was found at either location in densities between monocropped maize and maize mixed with millet, but pest densities were higher on maize than on millet. The latter might have been due to either lower oviposition rates of *C. partellus* females or due to an inferior suitability of millet to survival of young larvae. The low pest densities in the maize–millet–bean and maize–millet–bean–sorghum systems were probably mostly due to the low cereal to bean ratio.

The relative importance of *S. calamistis* on millet was high and it was equally important on monocropped millet and on maize in the maize–millet crop at Kiboko. This suggests that millet is the preferred host of *S. calamistis*. *S. calamistis* is of minor importance in East and Southern Africa (Wale 1999; Cugala and Omwega 2001; Nsami et al. 2001) but the major noctuid pest of maize in West Africa (Schulthess et al. 1997). Oloo and Ogeda (1990) recorded *C. partellus* larval density of 0.18 per plant in the sorghum–cowpea intercrop vs. 1.8 per plant in the sorghum–maize mixture; furthermore, intercropping maize with sorghum increased the level of stemborers in maize compared with pure stands of maize, while in sorghum infestation levels were similar in both systems. In the present study, *C. partellus* densities were four to five times higher on monocropped sorghum than on monocropped maize corroborating results by Ogwaro (1983). Jiang and Schulthess (2005) showed that the intrinsic rates of increase of *C. partellus* were ca 40% higher on sorghum than on maize and this was mostly the result of differences in fecundity. However, Amoako-Atta et al. (1983) found higher incidence of deadhearts caused by stemborers on maize than on sorghum indicating differences in the susceptibility between the two crops to borer feeding. Maize has a highly phasic growth pattern with a distinct vegetative and reproductive phase, and unlike sorghum it does not produce tillers (Peacock and Wilson 1984). Thus, maize cannot compensate for stem damage by producing tillers and is highly susceptible to borer attack. As shown by Berger (1992), dispersal of *C. partellus* larvae is density dependent. Thus, densities on maize may increase as a result of larval dispersal from sorghum. Consequently, intercropping maize with other cereal crops, that are suitable hosts of the target pests, is not advantageous in terms of pest reduction on the more susceptible crop. Furthermore, with alternate row arrangements of host and non-host plants, the ovipositing female and dispersing larvae move more easily within than between rows (Chabi-Olaye et al. 2005a,b). That is probably why with bean in the system stemborer densities were low.

In the present study, parasitism by *C. flavipes* significantly varied with cropping system and was highest in the systems consisting of more than two crop species. Getu et al. (2003) reported higher parasitism of *C. partellus*, when cereals were intercropped with haricot beans and cowpea and when wild grass hosts of stemborers were present, while Oloo and Ogeda (1990) found higher pupal mortality due to the ichneumonid *Dentichasmias busseolae* in sorghum–cowpea than in sorghum–maize. Higher egg parasitism was also found in the cassava–maize relay crops by Schulthess et al. (2004) and the trials by Chabi-Olaye et al. (2005a) in Cameroon; in these experiments parasitism decreased with host densities and they suggested that higher parasitism reported in mixed compared with monocropped cereals was mostly caused by density-dependent effects rather than by the higher attractiveness or suitability of diversified systems to parasitoids. This was also indicated by the negative relationship between parasitism and density shown in the present experiments. However, because the effect of predation on borer density has not been assessed in any of these studies the 'natural enemy hypothesis' cannot entirely be rejected.

Yields of maize varied with season, cropping system – which determined plant density – and location. As a result of drought, they were < 600 kg during the short rains of 2003 and over 4 ton in the maize–bean crop during the short rains in 2004. The main determinant for yield was plant density with the exception of the maize–bean mixtures, which tended to have the highest yields. However, with the high bean plant density one would expect a strong interspecific competition, which should reduce yields of maize. Eastern Kenya is a drought-prone region, and as shown by Kariaga (2004), in intercrops with maize, beans cover the ground surface fast and reduce evaporation compared with maize monocrops. Similarly, Trujillo-Arriaga and Altieri (1990) showed that in a maize–*Vicia faba*–*Cucurbita moschata* intercrop, water was used more efficiently than in the maize monocrop as a result of reduced soil water evaporation through increased shade. Furthermore, in Africa, maize fields are often only weeded when the weed density is high and maize plants show signs of deficiency (S. Hauser, International Institute of Tropical Agriculture, Yaoundé, Cameroon, personal communication). Intercropping of, especially, dicotyledons, that cover the soil fast, are known to enhance crop yield via weed suppression (Fischler and Wortmann 1999; Szumigalski and Van Acker 2005). Thus, there might have been synergism between beans and maize from which maize profited more than beans, whose yields were severely reduced when mixed with a cereal.

The LER is frequently used to demonstrate that intercropping produces a greater total biological productivity per unit area of land than monocropping. Amoako-Atta et al. (1983) obtained the highest LER of 1.45 with a maize–cowpea–sorghum mixture and 1.3 with sorghum–cowpea, while mixing maize with sorghum yielded an LER of 0.89 only as a result of high losses caused by *B. fusca* and *C. partellus*. Chabi-Olaye et al. (2005b) consistently obtained LER > 1 with lowest values of 1–1.35 for maize–soybean and highest of > 1.5 with maize–cassava mixtures. RVI followed the same trend with highest values of 3.5 for maize–cassava intercrops. Similarly, Schulthess et al. (2004) calculated LERs of 1.5–2.1 for a maize–cassava relay crop. In the present study, LERs and RVIs were consistently < 1, with the exception of the maize–bean system, thus the land use efficiency and productivity of mixed cropped cereal systems in eastern Kenya are exceedingly low.

When compared with reports from the literature, the effect of intercropping systems on pest densities is very variable: in many cases there was no effect and in some cases pest densities on the susceptible crop maize were increased. Thus, the advantage of such systems in terms of crop production in general is questionable. It is suggested that in regions where such systems are practised maize became a crop relatively recently and farmers may not have much experience with it. In addition, in eastern Kenya, droughts became more frequent in recent decades. Very likely in drought situations, cropping systems with millet and sorghum will be more profitable than monocropped maize because of the high susceptibility of this crop to drought and the risk of crop failure.

Acknowledgements

The authors wish to acknowledge the technicians who assisted with the fieldwork: Raymond Mokua, Patrick Onyango, Robert Mutweti and Daniel Mutisya. They also like to thank the Director of KARI for providing a conducive environment for the partnership between KARI and ICIPE, which facilitated implementation of this study. The work was funded by the Directorate General for International Cooperation, the Netherlands.

References

Adesiyun AA, 1983. Some effects of intercropping of sorghum, millet and maize on infestation by lepidopterous stalk-borers, particularly *Busseola fusca*. Insect Sci. Appl. **4,** 387–391.

Altieri MA, Letourneau DK, 1982. Vegetation management and biological control in agroecosystems. Crop. Prot. **1,** 405–430.

Amoako-Atta B, Omolo EO, Atta B, Amoak AD, 1983. Influence of maize, cowpea and sorghum intercropping systems on stem-/pod-borer infestations. Insect Sci. Appl. **4,** 47–57.

Ampong-Nyarko K, Seshu Reddy KV, Nyang'or RA, Saxena KN, 1994. Reduction of insect pest attack on sorghum and cowpea by intercropping. Entomol. Exp. Appl. **70,** 179–184.

Andow DA, 1991. Vegetational diversity and arthropod population response. Annu. Rev. Entomol. **36,** 561–586.

Anon. 1984. Climatological statistics for Kenya. Kenya Meteorological Department, Nairobi, Kenya.

Argwings-Kodeck G, Jayne TS, Nyambane G, Awuor T, Yamano T, 1998. How can micro level household information make a difference for agricultural policy making? Kenya Agricultural Marketing and Policy Analysis Project. Tegemeo Institute of Agricultural Policy and Development/Egerton University, Kenya Agricultural Research Institute, Michigan State University.

Berger A, 1992. Larval movements of *Chilo partellus* (Lepidoptera: Pyralidae) within and between plants: timing, density responses and survival. Bull. Entomol. Res. **82,** 441–448.

Bosque-Pérez NA, Mareck JH, 1991. Effect of the stemborer *Eldana saccharina* (Lepidoptera: Pyralidae) on the yield of maize. Bull. Entomol. Res. **81,** 243–247.

Cardinale BJ, Harvey CT, Gross K, Ives AR, 2003. Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. Ecol. Lett. **6,** 857–865.

Chabi-Olaye A, Nolte C, Schulthess F, Borgemeister C, 2005a. Abundance, dispersion and parasitism of the noctuid stem borer *Busseola fusca* (Fuller) in mono- and intercropped maize in the humid forest zone of southern Cameroon. Bull. Entomol. Res. **95,** 169–177.

Chabi-Olaye A, Nolte C, Schulthess F, Borgemeister C, 2005b. Relationships of intercropped maize, stem borer damage to maize yield and land-use efficiency in the humid forest of Cameroon. Bull. Entomol. Res. **95,** 417–427.

Cugala D, Omwega CO, 2001. Cereal stemborer distribution and abundance, and introduction and establishment of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) in Mozambique. Insect Sci. Appl **21,** 281–287.

Endrody-Younga S, 1968. The stem borer *Sesamia botanephaga* Tams & Bowden (Lep. Noctuidae) and the maize crop in central Ashanti, Ghana. Ghana. J. Agric. Sci. **1,** 103–131.

FAO 2000. FAOSTAT. http://faostat.fao.org. Last access date 10th November 2006.

Finch S, Collier RH, 2000. Host-plant selection by insects – a theory based on 'appropriate/inappropriate landings' by pest insects of cruciferous plants. Entomol. Exp. Appl. **96,** 91–102.

Fischler M, Wortmann CS, 1999. Green manures for maize—bean systems in eastern Uganda: agronomic performance and farmers' perceptions. Agrofor. Syst. **47,** 123–128.

Getu E, Overholt WA, Kairu E, Omwega CO, 2003. Evidence of the establishment of *Cotesia flavipes* (Hymenoptera: Braconidae), a parasitoid of cereal stemborers, and its host range expansion in Ethiopia. Bull. Entomol. Res **93,** 125–129.

Gounou S, Schulthess F, Shanower TG, Hammond WHO, Braima H, Cudjoe AR, Adjakloe R, Antwi KK, Olaleye I, 1994. Stem and ear borers of maize in Ghana. Plant Health Management Research Monograph No. 4. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Jaetzold R, Schmidt H, 1983. Farm management handbook of Kenya. Natural conditions and farm information. Volume 2, Part C. East Kenya. Ministry of Agriculture, Kenya.

Jiang N, Schulthess F, 2005. The effect of nitrogen fertilizer application to maize and sorghum on the bionomics of *Chilo partellus* (Lepidoptera: Crambidae) and the performance of its larval parasitoid *Cotesia flavipes* (Hymenoptera: Braconidae). Bull. Entomol. Res. **95,** 495–504.

Jiang N, Zhou G, Overholt WA, Muchugu E, Schulthess F, 2006. The temporal correlation and spatial synchrony in the stemborer and parasitoid system of Coast Kenya with climate effects. Ann. Soc. Entomol. Fr. **42,** (in press).

Kariaga BM, 2004. Intercropping maize with cowpeas and beans for soil and water management in Western Kenya. 13th International Soil Conservation Organization Conference. Australian Society of Soil Science and International Erosion Control Association, Australia.

Kruess A, Tscharntke T, 2000. Species richness and parasitism in a fragmented landscape: experiments and field studies with insects on *Vicia sepium*. Oecologia. **122,** 129–137.

Mgoo VH, Makundi RH, Pallangyo B, Schulthess F, Jiang N, Omwega CO, 2006. Yield loss due to the stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) at different nitrogen application rates to maize. Ann. Soc. Entomol. Fr. **42,** (in press).

Nsami E, Pallangyo B, Mgoo VH, Omwega CO, 2001. Distribution and species composition of cereal stemborers in the Eastern zone of Tanzania. Insect Sci. Appl. **21,** 347–351.

Ogwaro K, 1983. Intensity levels of stem-borers in maize and sorghum and the effect on yield under different intercropping patterns. Insect Sci. Appl **4,** 33–37.

Oloo GW, 1989. The role of local natural enemies in population dynamics of *Chilo partellus* (Swinh.) (Pyralidae) under subsistence farming systems in Kenya. Insect Sci. Appl. **10,** 243–251.

Oloo GW, Ogeda K, 1990. The incidence of *Chilo partellus* (Swinh.) (Pyralidae) and the contribution of natural enemies to its mortality under intercropping system in Kenya. Trop. Pest. Manage. **36,** 244–248.

Omwega CO, Kimani SW, Overholt WA, Ogol CKPO, 1995. Evidence of the establishment of *Cotesia flavipes* (Hymenoptera: Braconidae) in continental Africa. Bull. Entomol. Res. **85,** 525–530.

Overholt WA, Ngi-Song AJ, Omwega CO, Kimani-Njogu SW, Mbapila J, Sallam MN, Ofomata V, 1997. A review of the introduction and establishment of *Cotesia flavipes* Cameron in East Africa for biological control of cereal stemborers. Insect Sci. Appl. **17,** 79–88.

Peacock JM, Wilson GL, 1984. Sorghum. In: The physiology of tropical field crops. Ed. by Goldsworthy P, Fisher NM, John Wiley & Sons, New York, 249–279.

Piepho HP, 2004. An algorithm for a letter-based representation of all-pairwise comparisons. J. Comput. Graph. Stat. **13,** 456–466.

Piepho HP, Buchse A, Richter C, 2004. A mixed modelling approach for randomized experiments with repeated measures. J. Agron. Crop Sci. **190,** 230–247.

Risch SJ, Andews D, Altieri MA, 1983. Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions. Environ. Entomol. **12,** 625–629.

SAS. 2000. Users' guide: statistics, release 8.0. SAS Institute,, Cary, NC.

Schulthess F, Bosque-Pérez NA, Chabi-Olaye A, Gounou S, Ndemah R, Goergen G, 1997. Exchanging natural enemies species of lepidopterous cereal stemborers between African regions. Insect Sci. Appl. **17,** 97–108.

Schulthess F, Chabi-Olaye A, Gounou S, 2004. Multi-trophic level interactions in a cassava-maize mixed cropping system in the humid tropics of West Africa. Bull. Entomol. Res. **94,** 261–272.

Songa JM, Overholt WA, Mueke JM, Okello RO, 2001. Colonization of *Cotesia flavipes* (Hymenoptera: Braconidae) in stemborers in semi-arid eastern province of Kenya. Insect Sci. Appl. **21,** 289–295.

Songa JM, Overholt WA, Okello RO, Mueke JM, 2002. Control of Lepidopteran stem borers in maize by indigenous parasitoids in semi-arid areas of eastern Kenya. Biol. Agric. Hort. **20,** 77–90.

Stewart JI, Faught WA, 1984. Response farming of maize and beans at Katumani, Machakos district, Kenya: recommendations, yield, expectations and economic benefits. East. Afr. Agric. For. J. **44,** 29–51.

Szumigalski A, Van Acker R, 2005. Weed suppression and crop production in annual intercrops. Weed Sci. **53,** 813–825.

Thies C, Tscharntke T, 1999. Landscape structure and biological control in agroecosystems. Science **285,** 893–895.

Trujillo-Arriaga J, Altieri MA, 1990. A comparison of aphidophagous arthropods on maize polycultures and monocultures, in Central Mexico. Agric. Ecosyst. Environ. **31,** 337–349.

van Rensburg JBJ, 1988. Aspects of the injuriousness of the maize stalk borer, *Busseola fusca* (Fuller) (Lepidopetra: Nocutuidae). Bull. Entomol. Res. **78,** 101–110.

Vandermeer JH, 1989. The ecology of intercropping systems. Cambridge University Press, New York.

Wale M, 1999. Population dynamics of the stemborers *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller) and *Sesamia calamistis* attacking sorghum in central Ethiopia. Insect Sci. Appl. **19,** 149–156.

Zhou G, Baumgartner J, Overholt WA, 2001a. Impact of an exotic parasitoid on stemborer (Lepidoptera) populations dynamics in Kenya. Ecol. Appl. **11,** 1554–1562.

Zhou G, Overholt WA, Mochiah MB, 2001b. Changes in the distribution of Lepidopteran maize stemborers in Kenya from the 1950s to 1990s. Insect Sci. Appl. **21,** 395–402.

Author's address: Nanqing Jiang (corresponding author), International Centre of Insect Physiology and Ecology (ICIPE), PO Box 30772-00100, G.P.O., Nairobi, Kenya. E-mail: njiang@icipe.org

© 2007 ICIPE