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Effect of cropping systems on cereal stemborers in the cool-wet and semi-arid ecozones of the Amhara region of Ethiopia

M. Wale*†, F. Schulthess†, Eunice W. Kairu‡ and Charles O. Omwega†

**Amhara Regional Agricultural Research Institute, PO Box 8, Bahir Dar, Ethiopia, †International Center of Insect Physiology and Ecology, PO Box 30772-00100, Nairobi, Kenya and ‡Department of Biological Sciences, Pure and Applied Sciences, Kenyatta University, PO Box 43844, Nairobi, Kenya*

Abstract

1 Field experiments were conducted on maize and sorghum at three locations in the Amhara state of Ethiopia to determine the effects of mixed cropping on stemborer infestation, borer natural enemies and grain yields. In the cool-wet ecozone of western Amhara, sole maize was compared with maize intercropped with faba bean, mustard, potatoes and cowpea. In the semi-arid ecozone of eastern Amhara, the trial was conducted on both maize and sorghum with the companion crops haricot bean, sesame, cowpea and sweet potatoes.

2 The results showed that the predominant borer species in western and eastern Amhara were, respectively, *Busseola fusca* and *Chilo partellus*. In Addis Zemen, western Amhara, maize intercropped with mustard and potatoes had significantly lower pest numbers and percent tunnelling than other intercrops and the maize monocrop during the vegetative stage. In eastern Amhara, the cropping system did not significantly affect pest densities but damage to stem, ear or heads tended to be greatest when cereals were intercropped with sweet potatoes.

3 Parasitism of *C. partellus* by the braconid *Cotesia flavipes* was greater on maize than sorghum, and on maize it was greater with sweet potatoes than in other intercrops or sole maize. Cocoon mass number per plant did not vary significantly between treatments.

4 There were significant differences between treatments in yields of both sorghum and maize (per plant and per unit area) with the lowest yields observed when they were intercropped with a tuber crop.

5 The results suggest that simultaneous planting of the crop species selected has little advantage over monocropped maize.

Keywords Amhara, borer damage, cool-wet and semi-arid ecozones, intercrops, maize and sorghum, stemborers and natural enemies.

Introduction

Maize and sorghum are the most important grain crops grown by small-scale and commercial farmers in Africa (Food and Agriculture Organization of the United Nations, 2003). In Ethiopia, these crops are grown on approximately 2.4 million hectares (Central Statistical Authority, 2000; Central Agricultural Census Commission, 2003). Whereas maize thrives well in cool and wet intermediate altitudes (1500–2000 m above sea level), sorghum is the dominant crop in the lowlands (< 1500 m a.s.l.) (Birhane, 1977). Two stemborer species, the invasive *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and the indigenous *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) are the predominant pests of both crops (Assefa, 1985). Minor borers include *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae), *Sesamia nonagrioides botanephaga* Tams and Bowden and *Rhynchaenus niger* (Horn) (Coleoptera: Rhynchophoridae) (Emana, 2002; Melaku *et al.*, 2006). Reported crop losses in outbreak areas are in the range 15–100% (Assefa, 1989; Tadesse, 1989; Gashawbeza & Melaku, 1996; Emana, 1998; Wale *et al.*, 2006).

The exotic parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) has been reported from semi-arid

Correspondence: Melaku Wale, International Center of Insect Physiology and Ecology, PO Box 30772-00100, Nairobi, Kenya. Tel.: +251 (58) 3380237; fax: +251 (58) 3380235; e-mail: melakuwale@yahoo.com, mwale@icipe.org

eastern Amhara (Emana *et al*., 2003; Wale *et al*., 2006) after its introduction by the International Centre of Insect Physiology and Ecology (ICIPE) into Kenya in 1991 (Overholt *et al*., 1994) as part of a classical biological control programme that now encompasses 11 countries in East and Southern Africa. It probably invaded Ethiopia from Somalia, where it was introduced in 1997 (Emana *et al*., 2003).

In the past 10 years, research on options to control cereal stemborers in Africa has increasingly focused on biological control and habitat management. Habitat management techniques include management of soil nutrients (Sétamou *et al*., 1993, 1995; Mgoo, 2005; Wale *et al*., 2006), crop rotation (Chabi-Olaye *et al*., 2005a), trap plants (Schulthess *et al*., 1997; Ndemah *et al*., 2002) and mixed cropping (Schulthess *et al*., 2004; Chabi-Olaye *et al*., 2005b). African small-scale farmers traditionally practice intercropping to improve total land productivity and to overcome the impact of crop failure and falling prices in the market of any single crop (Norman, 1974; Risch *et al*., 1983; Vandermeer, 1989). Furthermore, diversified crop systems often reduce pest densities (Francis *et al*., 1976; Altieri & Letourneau, 1982; Baliddawa, 1985; Sheehan, 1986; Russell, 1989; Andow, 1991). In African subsistence cereal systems, intercropping is claimed to reduce pest infestation by up to 83% (Nwanze, 1997; Emana, 2002; Schulthess *et al*., 2004; Chabi-Olaye *et al*., 2005b). Mechanisms of pest reduction in mixed cropped subsistence cereal systems include trap plants, reduced host finding by the ovipositing female moth, increased natural enemy activity, or mortality due to starvation and/or predation of migrating larvae on nonhosts in the crop mixture (Adesiyun, 1979, 1983; Baliddawa, 1985; Dissemond & Hindorf, 1990; Oloo & Ogeda, 1990; Ndemah *et al*., 2002; Schulthess *et al*., 2004). Although intercropping is widely practiced in the Amhara state of Ethiopia, nothing is known about its effect on infestations of stemborers or on the performance of their natural enemies. Thus, the present work investigated multi-trophic level interactions in indigenous mixed cropping systems in the cool-wet and semi-arid ecozones of the Amhara state.

Materials and methods

Experimental sites

The study was conducted in 2004 in the Amhara National Regional State, which is located in northern part of Ethiopia, covering 170 000 km^2 between 8°45′N to 13°45′N and 35°46′E to 40°25′E (Planning and Economic Development Bureau, 1999). Rainfall gradually increases, together with altitude, from 300 mm in eastern Amhara to over 2000 mm in western Amhara. Much of the western part of the State receives more than 1200 mm rainfall during the only effective rainy season from June to September because it is situated in the windward side of the rain-carrying summer monsoon. By contrast, due to easterly winds, the eastern part has a bimodal rainfall distribution with a short rainy season in spring, in addition to the main rainy season from July to September. Trials were planted at three sites in two ecologically distinct regions, in Kola Diba and Addis Zemen in the cool-wet western Amhara region and at Chefa in the semi-arid eastern Amhara. The three locations were selected based on their relatively high borer infestation levels and accessibility. Geographic and climatic information, soil type, altitude, drainage and the predominant stemborer species of each location are given in Table 1.

In western Amhara, where sorghum is not intercropped, the experiments were conducted with maize only whereas, in eastern Amhara, the same set of experiments was conducted on both maize and sorghum. Eastern Amhara is characterized by a shorter rainy season and crop varieties mature earlier than in western Amhara.

Experimental set up

In western Amhara, the companion crops commonly used by farmers and in the present trials were Ethiopian mustard (*Brassica carinata* Braun) (Cruciferae) (var *Tul*), potato (*Solanum tuberosum* L.) (Solanaceae) (var *Tolcha*) and faba bean (*Vicia faba* L.) (Leguminasae) (var *CS-20 DK*) and a pulse crop new to the area [i.e. cowpea, *Vigna unguiculata* (L.) Walp. (Leguminasae) (var *Bekur*)]. Planting was carried out in mid-June and harvested at the end of November. In eastern Amhara, the companion crops were cowpea, sesame (*Sesamum indicum* L.) (Pedaliaceae) (var *Abasina*), haricot beans (*Phaseolus vulgaris* L.) (Fabaceae) (var *Wodo*), and sweet potato [*Ipomoea batatas* (L.) Lam. (Convolvulaceae) (var *Belela*)]. Planting was carried out in mid-July and harvested at the end of November. The maize variety was *BH 540* in western and *Katumani* in eastern Amhara; the sorghum variety was *Yeju*.

The trials were arranged in a randomized complete block design, replicated four times, with spacing for both crops of 0.75 m between and 0.30 m within rows. Spacing between replicates (blocks) and plots were 3 m and 2 m, respectively. The range of dispersal of young stemborer larvae is 0.3–0.7 m from the oviposition site (Päts & Ekbom, 1992); thus, interactions between treatments should be negligible. Plot size

Table 1 Geographic locations and some physiographic details of experimental sites

Location	Latitude	Longitude	Altitude (m)	Soil type	Drainage	Precipitation (mm)	Climate	Dominant borer species
Kola Diba	12°25′04″N	37°19′00′E	1842	Vertisol	Waterlogged	930.7	Cool-wet	*Busseola fusca*
Addis Zemen	12°04′07″N	37°43′41″E	1830	Nitosols	Well drained	745.1	Cool-wet	*Busseola fusca*
Chefa	10°51′20″N	39°48′56″E	1479	Vertisol	Waterlogged	658.8[a]	Semi-arid	*Chilo partellus*

[a]Only the main season from May to December.

was 6 × 6 m, with eight rows per plot. In plots with potatoes, the cereal density was 22 222 plants per ha whereas, for other intercrops and monocrops, it was 44 444 plants per ha. Potatoes were planted on alternate rows, with every other row planted with maize or sorghum. The other companion crops were planted in the middle between two cereal rows. Within row distance was 0.30 m for potatoes, 0.20 m for sesame, 0.15 m for mustard and 0.10 m for faba bean, haricot bean and cowpea. Both main crops and intercrops were planted at the same time.

Sampling procedures

Sampling was carried out at the vegetative stage, tasseling/heading, grain filling and harvest. Because of differences in germination rates, eight to ten plants per plot were sampled at the vegetative and grain filling stages, and 15–20 plants at harvest. After recording plant height and the diameter of each plant, the number of leaves, internodes, holes, damaged and undamaged internodes, and length of stem tunnelling were recorded. Each plant was dissected to determine the number of borers. The borers recovered were taken to the laboratory and reared on pieces of maize or sorghum stems until adult moths or parasitoid emergence.

Attention was given to the effect of the cropping system on parasitism by *C. flavipes* in the ecozone of its occurrence (i.e. the semi-arid ecozone). The cocoon masses collected were sent to ICIPE for identification of the *Cotesia* species.

At harvest, up to 20 plants per plot were dissected to determine borer density and damage, including maize cob damage and sorghum head chaffyness. Then, cob or head weight and grain yield of all plants in each plot were recorded.

Statistical analysis

An analysis of variance (ANOVA) was conducted using the general linear model (SAS Institute, 1999–2000) to assess the effects of various intercropping systems and crop growth stages on borer density and borer damage, and the effect of cropping system and crop species on percent parasitism and number of cocoon masses per plant, as well as differences in yield between cropping systems and locations. Stepwise regression analyses were carried out between cob and head weight and plant growth parameters, damage variables and borer density. For assessment of the effect of borers on plant growth variables, borer-days, defined as the mean number of borers observed on consecutive sampling occasions multiplied by the number of days between the samplings and then summed over the whole sampling period, was used (Sétamou *et al*., 1995). This measure was chosen, in addition to borer numbers, because it takes into consideration borer density as well as its duration of attack (Schulthess *et al*., 1991). Borer data were subjected to logarithmic transformation. Simple linear regression analysis was carried out between the dependent variables [i.e. percent parasitism and cocoon mass density (*C. flavipes*)] and the independent variables (i.e. borer density and borer-day across treatments for each crop type and growth stage).

Results

Effect of intercrops on stem borer density

In western Amhara, *B. fusca* was the major borer species. At Addis Zemen, plots intercropped with mustard and potatoes had significantly lower borer densities at the vegetative stage and borer-days than maize monocrop plots whereas differences among the other treatments were not significant. Across treatments, compared with the harvest period, pest densities tended to be higher at the vegetative stage at Addis Zemen and at grain filling at Kola Diba (Table 2).

In eastern Amhara, the major borer species was *C. partellus*. Borer density at both tasseling and harvest on both sorghum and maize did not vary with cropping system and the data are not shown here. Borer-days were 27.7–42.0 on maize and 75.8–114.4 on sorghum.

Effect of intercrops on larval parasitism of *C. partellus* by *C. flavipes*

Cotesia flavipes was found in the trials in eastern Amhara only and percent parasitism tended to be higher on maize than sorghum (Table 3). On maize, parasitism was highest with sweet potato and was similar on the remaining treatments. Parasitism on sorghum and number of cocoon masses on both sorghum and maize did not vary with treatment. Simple regression analyses of percent parasitism against borer density showed no significant relationship (F = 2.58, d.f. = 3, P = 0.2063, r^2 = 0.46).

Effect of intercrops on borer damage variables

In Addis Zemen, borer damage such as tunnelling and number of holes were highest at the vegetative stage and in Kola Diba at grain filling stage. In Addis Zemen, damage symptoms during the vegetative stage were lowest with mustard as the companion crop (Table 4); there was no consistent pattern at Kola Diba (Table 4). Percent cob damage was low and in the range 0.2–2.0% in Addis Zemen and 1.5–17.7% in Kola Diba (results not shown in the table). In Kola Diba, cob damage was highest in maize monocrop plots and similar in the other treatments (F =19.4, d.f. = 4,754, P < 0.0001).

In Chefa, tunnelling and number of holes were significantly higher at harvest than heading/tasseling stage (Table 5). At this stage, plots intercropped with sweet potatoes had significantly higher percent tunnelling and number of holes than the other treatments. Percent internode damage did not vary with treatments and the results are not shown; however, it was higher on sorghum than maize. On maize, percent cob damage did not significantly vary among treatments but percent chaffy heads on sorghum was significantly higher with sweet potato as the companion crop (Table 5).

Effect of intercropping on yield and its components

In Addis Zemen and Kola Diba, per plant maize cob weight was highest and per area yield lowest with potatoes (Table 6 and 7). In Addis Zemen, per ha yield was highest with

Table 2 The effect of indigenous intercrops on *Busseola fusca* density (± SE) per plant and borer-days on maize in the cool-wet ecozone of the Amhara state, Ethiopia

	Addis Zemen							Kola Diba						
	Borer density							Borer density						
Intercrops	Vegetative	Grain filling	Harvest	*F*	d.f.	*P*	Borer-days	Vegetative	Grain filling	Harvest	*F*	d.f.	*P*	Borer-days
Potatoes	0.20 ± 0.10^{bA}	0.06 ± 0.05^{aA}	0.10 ± 0.07^{aA}	0.45	2156	0.6408	5.5b	0.21 ± 0.07^{aA}	0.40 ± 0.08^{aA}	0.11 ± 0.03^{bA}	1.21	2229	0.2993	12.9
Mustard	0.05 ± 0.05^{cA}	0.00 ± 0.01^{aA}	0.03 ± 0.03^{aA}	0.25	2162	0.7804	1.1c	0.14 ± 0.073^{aA}	0.14 ± 0.17^{aA}	0.10 ± 0.04^{bB}	3.27	2241	0.0399	8.0
Faba bean	1.87 ± 0.40^{aA}	0.00 ± 0.05^{aB}	0.00 ± 0.01^{aB}	56.41	2146	<0.0001	21.8^{a}	0.40 ± 0.12^{aA}	0.25 ± 0.10^{aA}	0.21 ± 0.07^{aA}	0.86	2192	0.4230	15.0
Cowpea	0.80 ± 0.30^{bA}	0.11 ± 0.07^{aB}	0.00 ± 0.01^{aB}	14.86	2154	<0.0001	14.8^{a}	0.26 ± 0.09^{aAB}	0.45 ± 0.13^{aA}	0.12 ± 0.03^{bB}	5.97	2192	0.0030	16.1
Monocrop	1.00 ± 0.31^{bA}	0.01 ± 0.01^{aB}	0.07 ± 0.04^{aB}	17.71	2104	<0.0001	15.8^{a}	0.50 ± 0.25^{aA}	0.32 ± 0.17^{aA}	0.27 ± 0.06^{aA}	0.87	2186	0.4202	17.6
F	7.74	1.27	1.67				4.10	1.17	0.84	2.47				0.87
d.f.	4195	4178	4349				4,15	4198	4185	4657				4,15
P	<0.0001	0.2905	0.1555				0.0498	0.3271	0.5013	0.0433				0.5041

Means of borer density within a column followed by the same superscript lower case letter(s) and those within a row and a location followed by the same superscript upper case letter(s) are not significantly different at $P = 0.05$ [Student-Newman-Keuls test (SNK)]; means were calculated from four replicates at each crop growth stage; faba bean and monocrop stand for faba bean and monocrop maize, respectively.

Table 3 The effect of indigenous intercrops on percentage larval parasitism by *Cotesia flavipes* and cocoon mass density on maize and sorghum in the semi-arid ecozone of eastern Amhara, Ethiopia 2004

	% Larval parasitism by *Cotesia flavipes*							*Cotesia flavipes* cocoon masses/plant				
Intercrops	Maize	n_1	Sorghum	n_2	*F*	d.f.	*P*	Maize	Sorghum	*F*	d.f.	*P*
Sweet potatoes	20.00 ± 4.7^{aA}	140	0.56 ± 1.02^{aB}	261	3.90	1,119	0.0470	0.35 ± 0.11^{aA}	0.10 ± 0.04^{aA}	2.29	1,38	0.1381
Sesame	0.50 ± 3.3^{bA}	147	0.71 ± 0.77^{aA}	234	2.34	1,153	0.1278	0.13 ± 0.08^{aA}	0.03 ± 0.03^{aA}	2.37	1,73	0.1280
Haricot beans	0.00 ± 3.3^{bA}	115	0.50 ± 0.72^{aA}	244	0.24	1,157	0.6225	0.23 ± 0.08^{aA}	0.03 ± 0.03^{aB}	6.24	1,78	0.0144
Cowpeas	2.50 ± 3.3^{bA}	141	0.00 ± 0.72^{aB}	301	1.00	1,158	0.3188	0.08 ± 0.08^{aA}	0.00 ± 0.03^{aA}	3.16	1,78	0.0799
Maize monocrop	2.50 ± 3.3^{bA}	153	1.25 ± 0.72^{aA}	291	0.19	1,157	0.6614	0.23 ± 0.08^{aA}	0.03 ± 0.03^{aA}	0.84	1,78	0.0958
F	3.45		0.39					1.25	1.22			
d.f.	4375		4369					4175	4,170			
P	0.0096		0.8191					0.2933	0.3050			

Means within a column followed by the same superscript lower case letter(s) and means within a row followed by the same superscript upper case letter(s) are not significantly different at $P = 0.05$ (SNK). n_1, n_2, number of larvae collected on maize and sorghum, respectively.

Table 4 Effect of indigenous intercrops on borer damage variables on maize in the cool-wet western Amhara, Ethiopia

	Addis Zemen						Kola Diba					
Intercrops	Vegetative	Grain filling	Harvest	*F*	d.f.	*P*	Vegetative	Grain filling	Harvest	*F*	d.f.	*P*
% Stem tunnelling												
Potatoes	1.66 ± 0.98^{bA}	0.50 ± 0.38^{aAA}	0.15 ± 0.38^{aB}	1.72	2,143	0.1827	0.54 ± 0.33^{aB}	11.8 ± 3.24^{aA}	2.64 ± 0.64^{abA}	23.54	2,214	<0.0001
Mustard	0.43 ± 1.10^{bA}	0.17 ± 0.40^{aA}	0.22 ± 0.35^{aA}	0.16	2,151	0.8554	0.13 ± 0.33^{aB}	10.7 ± 3.32^{aA}	2.30 ± 0.64^{abB}	27.57	2,238	<0.0001
Faba bean	6.29 ± 1.27^{aA}	0.00 ± 0.38^{aB}	0.36 ± 0.38^{aB}	20.64	2,140	<0.0001	0.67 ± 0.34^{aB}	11.9 ± 3.32^{aA}	1.48 ± 0.72^{bB}	49.47	2,240	<0.0001
Cowpea	2.06 ± 1.10^{abA}	1.11 ± 0.36^{aA}	0.40 ± 0.38^{aA}	3.88	2,144	0.0228	1.13 ± 0.35^{aB}	9.1 ± 3.32^{aA}	1.86 ± 0.73^{abB}	15.18	2,252	<0.0001
Maize monocrop	3.89 ± 1.10^{abA}	0.14 ± 0.36^{aB}	1.23 ± 0.38^{aA}	6.84	2,144	0.0014	0.78 ± 0.34^{aB}	8.4 ± 3.41^{aA}	4.46 ± 0.75^{aA}	8.04	2,206	<0.0001
F	3.71	1.47	1.31				1.16	0.22	2.42			
d.f.	4195	4178	4349				4203	4200	4,757			
P	0.0075	0.2191	0.2657				0.3303	0.9270	0.0470			
Holes/plant												
Potatoes	1.16 ± 0.65^{abA}	0.50 ± 0.38^{aAB}	0.03 ± 0.09^{aB}	6.13	2,106	0.0030	0.36 ± 0.25^{aB}	4.10 ± 0.89^{aA}	0.76 ± 0.14^{aB}	19.63	2,234	<0.0001
Mustard	0.25 ± 0.73^{bA}	0.13 ± 0.40^{aA}	0.11 ± 0.08^{aA}	0.25	2,112	0.7780	0.05 ± 0.24^{aB}	3.80 ± 0.92^{aA}	0.57 ± 0.14^{aB}	26.41	2,241	<0.0001
Faba bean	3.80 ± 0.84^{aA}	0.00 ± 0.38^{aB}	0.10 ± 0.09^{aB}	29.46	2,96	<0.0001	0.70 ± 0.25^{aB}	3.60 ± 0.92^{aA}	0.52 ± 0.15^{aB}	20.73	2,197	<0.0001
Cowpea	2.15 ± 0.73^{abA}	1.00 ± 0.36^{aAB}	0.10 ± 0.09^{aB}	8.48	2,104	0.0004	0.89 ± 0.26^{aB}	3.55 ± 0.92^{aA}	0.54 ± 0.16^{aB}	20.12	2,192	<0.0001
Maize monocrop	2.80 ± 0.73^{abA}	0.11 ± 0.36^{aB}	0.23 ± 0.09^{aB}	14.20	2,104	<0.0001	0.33 ± 0.25^{aB}	2.26 ± 0.94^{aA}	0.78 ± 0.16^{aB}	5.97	2,186	0.0031
F	3.27	1.24	0.71				1.77	0.57	0.68			
d.f.	4195	4178	4349				4203	4203	4,757			
P	0.0480	0.3020	0.5820				0.1355	0.6824	0.6077			
% Internode damage												
Potatoes	5.69 ± 2.65^{ab}	–	0.23 ± 0.44^{a}				3.67 ± 2.23^{a}	–	4.67 ± 0.76^{a}			
Mustard	0.62 ± 2.96c	–	0.68 ± 0.40^{a}				0.33 ± 2.21^{b}	–	3.11 ± 0.75^{b}			
Faba bean	15.4 ± 3.41a	–	0.33 ± 0.44^{a}				6.92 ± 2.29^{a}	–	2.22 ± 0.85^{b}			
Cowpea	8.2 ± 2.96^{ab}	–	0.47 ± 0.43^{a}				7.28 ± 2.35^{a}	–	2.66 ± 0.86^{b}			
Maize monocrop	9.6 ± 2.96^{ab}	–	1.19 ± 0.43^{a}				5.31 ± 0.89^{a}	–	5.31 ± 0.89^{a}			
F	2.97	–	0.78				1.56	–	2.49			
d.f.	4195	–	4349				4334	–	4,757			
P	0.0235	–	0.5399				0. 1869	–	0.0419			

Means of damage variables within a column followed by the same superscript lower case letter(s) and those within a row within a location followed by the same superscript upper case letter(s) are not significantly different at $P = 0.05$ (SNK).

Table 5 Effect of indigenous intercrops on borer damage variables on maize and sorghum in Chefa in the semi-arid eastern Amhara, Ethiopia

	Maize					Sorghum				
Intercrops	Tasseling stage	Harvest	*F*	d.f.	*P*	Heading stage	Harvest	*F*	d.f.	*P*
% Stem tunneling										
Sweet potatoes	0.77 ± 00.16^{aB}	4.28 ± 2.39^{aA}	11.52	1,69	0.0012	1.53 ± 0.31^{aB}	49.22 ± 5.00^{aA}	276.80	1,58	<0.0001
Sesame	0.00 ± 00.17^{bB}	8.83 ± 1.69^{aA}	17.01	1,78	<0.0001	0.00 ± 0.31^{bB}	46.19 ± 3.80^{aA}	146.10	1,73	<0.0001
Haricot beans	0.10 ± 00.17^{bB}	9.14 ± 1.69^{aA}	26.27	1,77	<0.0001	0.00 ± 0.31^{bB}	33.65 ± 3.55^{aA}	93.41	1,78	<0.0001
Cowpeas	0.20 ± 00.17^{bB}	7.26 ± 1.69^{aA}	16.78	1,78	0.0001	0.17 ± 0.31^{bB}	43.48 ± 3.55^{aA}	145.55	1,78	<0.0001
Monocrop	0.35 ± 00.17^{bB}	5.69 ± 1.69^{aA}	15.96	1,78	<0.0001	0.12 ± 0.31^{bB}	43.09 ± 3.55^{aA}	136.47	1,78	<0.0001
F	3.35	1.13				4.62	2.26			
d.f.	4195	4175				4195	4,170			
P	0.0111	0.3451				0.0014	0.0646			
No. Holes/plant										
Sweet potatoes	0.39 ± 0.27^{aB}	3.75 ± 0.94^{aA}	11.52	1,59	0.0012	0.75 ± 0.18^{aB}	7.25 ± 1.07^{aA}	276.80	1,58	<0.0001
Sesame	0.38 ± 0.28^{aB}	3.65 ± 0.94^{aA}	17.01	1,78	<0.0001	0.05 ± 0.18^{bB}	5.06 ± 0.81^{aA}	146.09	1,73	<0.0001
Haricot beans	0.46 ± 0.28^{aB}	2.90 ± 0.66^{aA}	26.27	1,77	<0.0001	0.00 ± 0.18^{bB}	6.90 ± 0.75^{aA}	93.41	1,78	<0.0001
Cowpeas	0.30 ± 0.28^{aB}	2.48 ± 0.66^{aA}	16.78	1,78	0.0001	0.08 ± 0.18^{abB}	5.33 ± 0.75^{aA}	145.55	1,78	<0.0001
Monocrop	0.53 ± 0.28^{aA}	1.45 ± 0.66^{aA}	15.96	1,78	0.0001	0.10 ± 0.18^{abB}	6.58 ± 0.75^{aA}	136.47	1,78	<0.0001
F	0.10	1.77				3.12	1.35			
d.f.	4195	4175				4195	4,170			
P	0.9835	0.1378				0.0161	0.2525			
% Cob damage/chaffyness										
Sweet potatoes	–	0.05 ± 0.34^{a}				–	31.5 ± 3.81^{a}			
Sesame	–	0.20 ± 0.24^{a}				–	9.6 ± 2.88^{b}			
Haricot beans	–	0.58 ± 0.24^{a}				–	7.4 ± 2.69^{b}			
Cowpeas	–	0.13 ± 0.24^{a}				–	11.2 ± 2.69^{b}			
Monocrop	–	0.43 ± 0.24^{a}				–	9.0 ± 2.69^{b}			
F	–	0.70				–	7.75			
d.f.	–	4175				–	4,170			
P	–	0.5899				–	< 0.0001			

Means of damage variables within a column followed by the same superscript lower case letter(s) and those within a row within a crop type followed by the same superscript upper case letter(s) are not significantly different at $P = 0.05$ (SNK). Cob damage and chaffyness refer to maize and sorghum, respectively.

Table 6 Effect of intercrops on cob (g/plant) and grain yield (kg/ha) (± SE) of maize and sorghum in the cool-wet ecozone of the Amhara state

	Maize cob weight (g/plant)		Maize grain yield (kg/ha)	
	Addis Zemen	Kola Diba	Addis Zemen	Kola Diba
Potatoes	115.9 ± 12.7[a]	117.0 ± 5.5[a]	735.4 ± 197.70[c]	1882.2 ± 377.60[b]
Mustard	65.6 ± 8.2[b]	95.6 ± 6.0[b]	1400.9 ± 544.76[b]	2261.2 ± 222.10[a]
Faba bean	81.1 ± 8.4[b]	66.3 ± 4.7[c]	1613.2 ± 328.60[b]	2447.7 ± 300.81[a]
Cowpea	64.4 ± 8.0[b]	64.3 ± 3.5[c]	2168.8 ± 538.21[a]	2600.3 ± 357.76[a]
Maize monocrop	50.8 ± 7.4[b]	82.7 ± 5.6[b]	1015.4 ± 354.46[b]	2130.6 ± 171.92[a]
F	7.08	17.70	4.68	3.12
d.f.	4325	4,738	4,15	4,15
P	<0.0001	<0.0001	0.0310	0.0423

Means of cob weigh or grain weight within a column followed by the same superscript letter(s) are not significantly different at $P = 0.05$ (SNK).

cowpea whereas no differences between treatments were found in Kola Diba. In Chefa, the cropping system had no effect on sorghum head weight whereas the lowest per area yields for both maize and sorghum were obtained with sweet potato as the companion crop. For both crops, the differences among the other treatments including maize monocrops did not vary significantly.

Relationship between plant growth, borer density, parasitism, borer damage and yield

In western Amhara, stem diameter (x_1) was positively and percent tunnelling (x_2) and percent cob-damage (x_3) negatively related with yield: $y = 76.2x_1 - 1.3x_2 - 0.27x_3 - 7.3$, $n = 1069$, $P < 0.0001$, partial $r^2 = 0.281$, 0.023 and 003, respectively). In eastern Amhara, only stem diameter (x_1) and percent tunnelling (x_2) were significant: $y = 34.0x_1 - 0.96x_2 - 82.5$, $n = 351$, $P < 0.0001$, partial $r^2 = 0.09$ and 0.06, respectively.)

On both maize and sorghum across treatments, simple linear regression analyses of larval parasitism and cocoon masses per plant with *C. partellus* density (at tasseling and harvest stages) and borer-day revealed no significant relationships ($F = 0.42$, d.f. = 3, $P = 0.5634$, $r^2 = 0.12$).

Discussion

In western Amhara, significantly lower borer densities compared with maize monocrops were observed on potato and mustard plots at Addis Zemen, but only during the vegetative stage. By contrast, in eastern Amhara, borer attacks did not vary significantly between cropping systems. In western Africa, lower pest densities in intercrops were also found in relay-cropping of maize with cassava or grain legumes (Ndemah *et al*., 2003; Schulthess *et al*., 2004; Chabi-Olaye *et al*., 2005b). It was suggested that the nonhost plants reduced the host finding ability of the ovipositing female moth. The lack of differences in most treatments in the present study might have been due to the simultaneous planting of all crop species as also practiced by farmers. As a consequence, most companion crops, except for mustard, were not tall enough to reduce host finding capacity by the ovipositing female moth. Furthermore, young instar larvae of both *B. fusca* and *C. partellus* migrate by first moving to the whorl of the plants and then ballooning off to neighbouring plants. Thus, intercropping of a cereal with nonhost plants should decrease the chance of the migrating larvae to land on a suitable plant, leading to high mortality (Chabi-Olaye *et al*., 2005b). As larval dispersal can be expected to be density dependent (Berger,

Table 7 Effect of intercrops on cob (g/plant) and grain yield (kg/ha) (± SE) of maize and sorghum in the semi-arid ecozone of the Amhara state (Chefa)

	Maize cob weight (g/plant)	Sorghum head weight (g/plant)	Maize grain yield (kg/ha)	Sorghum grain yield (kg/ha)
Sweet potatoes	180.0 ± 14.9[a]	113.1 ± 9.9[a]	713.8 ± 47.6[b]	955.5 ± 30.4[b]
Sesame	116.6 ± 6.1[b]	97.6 ± 5.4[a]	1707.7 ± 241.4[a]	2377.3 ± 173.9[a]
Haricot beans	134.4 ± 8.2[b]	98.5 ± 5.0[a]	1698.9 ± 211.2[a]	1758.4 ± 172.6[a]
Cowpeas	127.1 ± 6.5[b]	95.2 ± 4.9[a]	1727.9 ± 85.2[a]	2029.9 ± 262.8[a]
Monocrop	134.4 ± 7.4[b]	111.6 ± 5.2[a]	1468.8 ± 105.7[a]	2444.3 ± 213.5[a]
F	6.20	2.05	7.56	10.34
d.f.	4174	4170	4,15	4,15
P	0.0001	0.0895	0.0015	0.0003

Means of cob weigh or grain weight within a column followed by the same superscript letter(s) are not significantly different at $P = 0.05$ (SNK).

1989, 1993; Päts & Ekbom, 1992), the high borer densities in eastern Amhara combined with the low growth habit of the companion crops during the vegetative stage of maize may have resulted in similar borer densities in all cropping systems. In the present study, only potatoes and mustard reduced pest densities. In the case of potato, the lower density of the host plant may have reduced the chances of migrating young larvae to land on a suitable host plant, thereby increasing immature mortality. Furthermore, strongly smelling plants, such as garlic, onion, coriander and tomatoes, have been shown to prevent pest buildup (Listinger & Moody, 1976). Ethiopian mustard contains high levels of long-chain monounsaturated fatty acids, mainly erucic acid, which is detrimental to human health upon consumption (Tsige *et al*., 2004). However, its effect on insects is not known.

In eastern Amhara, *C. partellus* parasitism by *C. flavipes* was highest in plots intercropped with sweet potatoes. Earlier studies in central Ethiopia showed higher parasitism on maize and sorghum intercropped with haricot bean (Emana, 2002). Host preference studies by Ngi-Song *et al*. (1996), Skovgard & Päts (1996) and Rutledge & Wiedenmann (1999) revealed differences between host plants in their attractiveness to parasitoids of cereal stemborers. Also, in West Africa, the scelionid *Telenomus isis* (Polaszek) attacked more *S. calamistis* eggs offered on maize and sorghum than eggs on millet or eggs offered without host plant (Chabi-Olaye *et al*., 2001). Also, depending on the cultivar, *Melinis minutiflora* Beauv. (Poaceae) was either deterrent or attractive to *Cotesia sesamiae* (Cameron) (Gohole *et al*., 2003a, b). Thus, higher parasitism described by Khan *et al*. (2001), when the companion crop was a nonhost of stemborers, could be due to density dependent effects (i.e. negative relationship between parasitism and host density) as was also shown for scelionid parasitoids attacking eggs of *B. fusca* and *S. calamistis* (Sétamou & Schulthess, 1995; Chabi-Olaye *et al*., 2005c) or attractiveness of the nonhost to the parasitoids as suggested by Khan *et al*. (1997). Density dependence did not play a role in the case of sweet potatoes and olfactometer studies are required to elucidate the mechanism behind the increased parasitization rates.

Cotesia flavipes parasitism of *C. partellus* was greater on maize than sorghum, corroborating the findings obtained by Ngi-Song *et al*. (1996), Jiang & Schulthess (2005) and Sétamou *et al*. (2005). The reasons proposed to explain this were the differences in suitability of larvae as affected by host plant species and quality; *C. flavipes* is a koinobiont (i.e. parasitized host larvae continue to feed during development of the immature parasitoid within the host). Thus, the species and thereby quality of the host plant might not only affect the host larvae, but also the parasitoids.

Per area yields tended to be lowest when cereals were planted with a root crop. For potato, this was due to the lower plant density of maize whereas, for sweet potato, this was probably the result of high interspecific competition between the tuber and the cereal crop, which also leads to an increased mortality of maize plants at an early growth stage. Schulthess *et al*. (2004) reported zero yield effects for a cassava-maize relay crop, where maize plant densities were the same in both maize monoculture and mixed crop plots. However, if the plants were treated with insecticides, yields were greater in monoculture than mixed cropped plots, suggesting that for untreated maize in intercropping the benefit of reduced pest densities equaled the negative effect of interspecific plant competition. In trials by Chabi-Olaye *et al*. (2005b), where maize was mixed with cassava, cowpea and soybean, the reduction in maize yields compared with maize monoculture could be related to the proportion of maize plants in the cropping system. However, reductions were much higher in insecticide-treated than nontreated plots, corroborating the results obtained by Schulthess *et al*. (2004).

In Addis Zemen, maize intercropped with cowpea produced greatest yields followed by maize intercropped with faba bean. Similarly, earlier agronomy studies in the same area showed that faba bean intercropped plots had 37–61% more grain yield than maize alone (Minale *et al*., 2001). In addition, Songa (Kenyan Agricultural Research Institute, Nairobi, Kenya, personal communication) found increased yields in a bean-maize intercrop and attributed this to reduced evaporation of soil water (Trujillo-Arriaga & Altieri, 1990; Kariaga, 2004) and weed suppression (Fischler & Wortmann, 1999).

In western Amhara, stepwise regression analyses showed a positive relationship between yield and plant height and stem diameter, but yields were negatively related with tunnelling and borer density, corroborating previous reports on African borer species (Bosque-Pérez & Mareck, 1991; Sétamou *et al*., 1995; Ndemah *et al*., 2000; Ndemah *et al*., 2001; Ndemah & Schulthess, 2002; Chabi-Olaye *et al*., 2005b). In general, borer densities declined towards harvest. Consequently, and as also suggested by Sétamou *et al*. (1995) and Chabi-Olaye *et al*. (2005b), borer density at harvest is not a reliable indicator of the pest load that a crop was exposed to because some borers had emerged to adults or been killed by natural enemies. Thus, stem tunnelling is a better indicator of pest damage and should be used in production equation to estimate yield loss on a regional basis as proposed by Gounou *et al*. (1994) and Cardwell *et al*. (1997).

In the present study, the effect of mixed cropping, with the exception of mustard and potatoes, on pest infestations was not as clear-cut as that observed in similar studies in western Africa. However, by contrast to the present study, Schulthess *et al*. (2004) relay-cropped maize with fast-growing cassava varieties and Chabi-Olaye *et al*. (2005b) planted both cassava and leguminous crops before maize. The planting sequence and growth habit of companion crops, as well as the growth cycle of the cereal, are the determinant factors responsible for the differences in pest infestations between the various studies. In the present trials, cereal yields were mostly not affected by the companion crops, indicating that the total land use efficiency was much higher in intercrops than monocrops. Hence, future trials should investigate relay-cropping where maize or sorghum is planted after the companion crop. Emphasis should be given to cereal-mustard systems because mustard, besides suppressing pest densities, is a high value crop. Furthermore, an insecticide treatment should be included to assess the efficiency of a cropping system in terms of yield under both low and high pest infestations.

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