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Efficacies of habitat management techniques in managing maize stem borers in Ethiopia

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Abstract

Habitat management techniques to control maize stem borers were tested in eastern (Melkassa and Mieso) and western (Sibu-Sire) Ethiopia. These techniques consisted of using mixed cropping of maize with haricot beans at different maize:bean ratios and a ‘‘push–pull’’ (PP) strategy utilizing Napier grass as a trap plant around maize plots as the ‘‘pull’’ and Desmodium in between maize rows as a deterrent or ‘‘push’’. In Melkassa, pest infestations were too low for the cropping system to significantly affect pests, plant damage and yields while in Mieso, where the pest densities were high, intercropping of maize with beans at ratios of 1:1 to 2:1 significantly decreased borer densities compared to pure maize stands. *Chilo partellus* (Swinhoe) and *Cotesia flavipes* (Cameron) were the major stem borer and parasitoid species, respectively, recorded both at Melkassa and Mieso. Borer parasitism was higher at Mieso than at Melkassa and it tended to increase with the increase of haricot bean ratio in the intercropping system. Land equivalent ratios of >1 indicated higher land use efficiency in mixed compared to sole cropping, even if pest densities were low. Establishment of Desmodium and Napier grass in PP trials varied from site to site, and poor establishment was observed in plots with low soil pH. Where yields varied significantly, they were lower in the PP than the sole maize plots. Borer densities were low and mostly not affected by the cropping system. However, in the second season when borer density was relatively high, higher levels of infestation and leaf feeding scores were recorded in the control than push–pull plots.

Keywords: Intercropping, Push–pull, Maize, Stem borers, Napier grass, Desmodium

1. Introduction

Maize and sorghum are the major cereal crops grown in Ethiopia. They rank second and third in terms of area coverage, after teff (*Eragrostis tef* (Zucc.) Trotter), and first and second in terms of yield/ha, and total production, respectively (CSA, 1997). Although these crops are very important in the country, average yields are very low due to various biotic and abiotic stresses. Among the major biotic constraints are lepidopteran stem borers such as the noctuid *Busseola fusca* Fuller and the crambid *Chilo partellus* (Swinhoe) which cause 25–100% yield loss (Emana and Tsedeke, 1990; Gashawbeza and Melaku, 1995; Assefa, 1998; Getu et al., 2001). Stem borers attack almost all plant parts including leaves, stems, tassels and ears. In the past, national and international agricultural research institutions have put major research emphasis on host plant resistance (Bosque-Pérez et al., 1997), biological control (Schulthess et al., 1997; Zhou et al., 2001), habitat management technologies based on management of soil nutrients (Sétamou et al., 1993), trap plants (Ndemah et al., 2002) and mixed cropping (Chabi-Olaye et al., 2005a). Khan et al. (2001) also mentioned that several plants have been identified as trap or push plants against stem borers that can be used in a push–pull strategy. Napier grass (*Pennisetun purpureum* (Schumach)) and Sudan grass (*Sorghum vulgare* var. sudanese Hitchcock) have shown potential to be used as trap plants whereas silver leaf desmodium (*Desmodium unicinatum* (Jacq.)) and greenleaf desmodium (*Desmodium introtum* (Evans)) repel ovipositing female stem borers.

Farmers in Africa traditionally practice intercropping to achieve greater land productivity and as insurance in case of crop failure (Vandermeer, 1989). In Ethiopia farmers intercrop maize and sorghum with sesame, haricot bean, sweet potato, mustards, and sometimes other cereals, depending on the region (Getu, 2002). Sasakawa Global

2000 (SG2000), which is a non-governmental organization, is trying to demonstrate this push–pull technology in Sibu-Sire Wereda of Oromia region where maize is the major crop grown in the area. The objectives of the present study were: 1) to determine the effect of intercropping of maize with haricot bean on yield and infestation by stem borers and suggest an appropriate ratio of crop mixtures, and 2) to evaluate the efficacy of the push–pull technology in reducing pest densities and increase maize yields.

2. Materials and methods

2.1. Intercropping experiment

Effect of intercropping of maize with haricot bean on infestation of maize by stem borers and borer parasitism was studied in a field experiment during the 2004 and 2005 cropping seasons at Melkassa and in 2005 at Mieso. Since infestations at Melkassa in 2004 were low, the experiment was repeated both at Melkassa and Mieso in 2005. Melkassa is located in the Central Rift Valley of Ethiopia (latitude 8° 24′ N; longitude 39° 11′ E; Altitude 1550 m above sea level (m asl)). It receives mean annual rainfall of 763 mm 70% of which falls during the major cropping season from June to September. Mean annual temperatures are in the range of 13.9–28.5 °C. Mieso is also located in the Central Rift Valley zone of the country about 150 km east of Melkassa with latitude 9° 20′ N; longitude 41° 11′ E, and altitude of 1470 m (m asl). The area receives 541 mm mean annual rainfall and the mean minimum and maximum temperatures are 14.6 and 30.4 °C respectively. The meteorological data mentioned above for the two experimental locations are long-term averages (20 years). Crop varieties Melkassa-1 (maize) and Awash-1 (haricot bean) were planted on 6 m long and 9 m wide plots at maize:bean row ratios of 1:1 to 4:1. In addition, both crops were planted as monocultures. In all treatments, maize was planted at 75 and 25 cm distances apart between and within rows, respectively, and kept at the same density in all treatments. There were 12 rows of maize in all mono or intercropped maize plots. In haricot bean alone plots, seeds were planted at distance apart of 40 cm between rows and 10 cm within rows. In the intercropped plots, haricot bean was planted within the available space between maize rows at maize:- bean rows ratios of 1:1 to 4:1. In all plots yield and other data were collected from the central 6 m × 6 m area of each plot to exclude edge effects. Each treatment was replicated 3 times in a completely randomized block design. Both crops were planted simultaneously at both sites. Diammonium phosphate and urea was applied at the rate of 100 kg/ha at planting and knee height of maize (4–5 weeks after planting), respectively. Leaf feeding score and percentage infestation was recorded three times during the vegetative stages of maize i.e. at 18, 40 and 60 days after emergence of the maize plants. Leaf feeding scores are recorded using a 1–9 scale as described by Sharma et al. (1992) where 1 denoted healthy and 9 heavily damaged plants. Leaf feeding scores were based on severity of feeding punctures and scratches on the leaves of individual plants as well as number of plants infested within the plot. The percentage infested plants was determined from the central 6 × 6 m area. Five plants per plot were randomly sampled, dissected and checked for stem borer damage, stem borer life stages and borer parasitism.

Data on borer density and parasitism was recorded at grain filling and at harvest. Pupae were kept in plastic Petri dishes (15 mm diameter with a moist tissue) until adult borer or parasitoid emergence. Larvae were reared on fresh maize or sorghum stalks that are cut from the field and new stalks were changed every 3 days until adult borer or parasitoid emergence. Parasitism was expressed as the percentages of suitable life stages (older than 2nd instar for larval and pupa for pupal parasitoids) parasitized. Parasitoids were kept in 70% ethyl alcohol and sent to the International Center of Insect Physiology and Ecology for identification. At harvest, yield data, stand count, plant height and stem diameter and insect damage parameters including percent infestation, tunnel length, and numbers of exit holes, percent cob damage, and borer density were recorded. Percent infestation was calculated from the whole plants within the sampling area (6 m × 6 m) while other stem borer damage parameters at harvest were recorded from 5 randomly sampled plants from each plot. Moreover, at harvest, percent cob damage by stem borers for each cob was assessed by comparing the surface area damaged by stem borer to the total surface area of the cob. Harvested cobs were kept in cloth bags, sun-dried, threshed and the seed was weighed when the moisture content reached 12–13%. Land equivalent ratio (LER), was calculated as described by Mead and Willey (1980) to estimate land use efficiency and productivity of the different intercropping systems.

$$LER = (I_m/M_m) + (I_{hb}/M_{hb})$$

where I_m and I_{hb} are the yields of maize and haricot bean, respectively, in the intercrops, and M_m and M_{hb} are the same yields in the monocrops. Monetary income per hectare was calculated using the retail market price of both crops (in Ethiopia birr) during January to March 2005.

2.2. Push–pull experiment

This experiment was conducted in collaboration with Sasakawa Global 2000 and Ministry of Agriculture and Rural Development of Oromia Regional State, Sibu-Sire Woreda, Ethiopia. Seven sites each of 0.5 ha were selected on farmers' fields out of which 0.25 ha was planted with maize along with Napier grass and Desmodium (push–pull plots or treated plots) in the 2004 and 2005 cropping season and the remaining 0.25 ha was planted with maize alone without Napier grass and Desmodium and used as control. Napier grass was planted around the plots in 3 rows of 50 cm width about 3 weeks before planting of maize. Desmodium was planted in between maize rows at the time of maize planting. For both plots, DAP and urea (46% N) was applied at planting and knee height of maize, respectively, at the rate of 100 kg/ha. Maize was planted at a spacing of 75 and 25 cm between and within rows, respectively. Cultural practices like weeding were done according to the farmers practice. However, better weeding and management was done in the control than push–pull plots due to the difficulty of weeding and hoeing in plots with Desmodium. Soil samples from each plot were taken for determination of soil pH after we observed variability in establishment of the PP plants as well as the maize plants. The soil samples were taken at three different depths (15, 30 and 45 cm). Four samples per plot (one sample from each quadrant of the plot) were sampled. Then, one composite sample from each depth per plot was taken and laboratory analysis was done for each of them. Each plot was divided into 4 quadrants and, 4 quadrants of 4m_4 m size were sampled from each plot to calculate yield and percent infestation. Moreover, 20 random plants per plot (10 plants from each diagonal) were sampled for plant morphological data and stem borer damage parameters and same data were collected as in the intercropping experiment. Ten Napier grass plants were randomly sampled and from each ten tillers were examined for the presence or absence of stem borer eggs and larvae. The establishment of Napier grass and Desmodium was scored on 1–5 scales based on growth and area coverage (1 = poor, 2 =medium, 3 =good, and 4–5 = very good). For convenience of data analysis, scores 1 and 2 were considered as poor establishment and 3–5 as good establishment of the PP plants.

For both experiments, data were analyzed using the Proc GLM procedure of SAS (SAS Institute, 1999) and whenever ANOVA showed significant differences between treatments, means were separated using Student Newman Keuls test (SNK) procedure. Data distribution was checked using the box plot and, when necessary, percent and count data were transformed using arcsine and square root transformations, respectively, before subjected to analysis soil pH data was log transformed. Correlation and regression analysis was performed to assess the relationship between the different variables measured. The significance level was set at P =0.05.

3. Results

3.1. Intercropping experiment

Percent stem borer infestations were low during both sampling periods and seasons at Melkassa and did not show statistically significant differences among treatments. Similarly, leaf feeding scores did not vary significantly with treatment except at 40 days after emergence (DAE) in 2004 but there were not clear trends with cropping system (Table 1). *C. partellus* accounted for 98.6% of the total borers recorded while the rest 1.4% was *Sesamia calamestis* (Hampson). At Mieso, pest densities were considerably higher than at Melkassa (Table 2) and both percent infestation and leaf feeding differed significantly between treatments at 18 and 60 DAE and were higher in monocropped maize (Table 1). *C. partellus* and *S. calamestis* constitute 92.8

and 7.2%, of the total stem borers recorded at Mieso, respectively. At both locations, borer parasitism did not differ between treatments (Table 2); the major parasitoid was the exotic braconid larval parasitoid *Cotesia flavipes*. Cameron which was responsible for 87.5 and 100% of overall larval parasitism at Mieso and Melkassa, respectively. At Mieso, 12.5% of larval parasitism was due to *Dolichogenidea fuscivora* (Walker) and larval parasitism by both parasitoids on medium to larger borers (3–5 larval stages) varied from 40% (for sole maize) to 100% in intercropping systems. *Pediobius furvus* (Gahan) and *Dentichasmias busseolae* (Heinrich) were the only pupal parasitoids recorded on *C. partellus* both at Melkassa and Mieso but the level of parasitism was less than 3% at both sites and in both seasons. At harvest at Melkassa, there were no significant differences in borer damage and numbers as well as yield with different maize:bean ratios (Table 3). However in Mieso, where borer infestations were high compared to Melkassa, borer damage and density tend to be highest in sole maize and they tended to increase with the proportion of maize in the mixture (Table 3). No significant difference was observed between treatments in terms of plant height, diameter, and stand count of maize plants at harvest for both sites and seasons. The LER for both intercropping experiments was >1 except for the plots with (4M:1 HB) ratios in Melkassa during both years (Table 4). Planting of maize in combination with haricot bean or alone gave better economic yields than haricot bean alone (Table 4).

3.2. Push–pull experiment

In the push–pull plots at the vegetative stage, higher percent infestation and leaf feeding scores were recorded in the control plots than push–pull (treated) plots (Fig. 1). However, there was no significant difference in yield and percent infestation between the control and push–pull plots in both the 2004 (Fig. 2A) and the 2005 (Fig. 2B) cropping seasons. Generally yields were low in plots with a low pH or in plots with poor establishment of Napier grass and Desmodium (Table 6). Establishment of Desmodium and Napier grass varied from site to site, and poor establishment was observed in plots with a lower pH (acidic soils) (Table 6). In the 2004 cropping season, the treated and control plots also did not differ in terms of percent stem tunneling, number of holes and borer density/plant or percent cob damage (Fig. 3A). However, in the following season (2005), a higher percentage of stem tunneling, exit holes/plant and borers per plant was recorded from plots with pure maize stand than plots with push–pull plants (Fig. 3B). We have also compared the treatments within and between plots with poor and good establishment of Napier and Desmodium. There was no significant difference between control and treated plots in terms of yield, insect damage parameters and soil pH (Table 5). Yields were positively correlated with plant height and diameter (r = 0.65, P< 0.0001 and r = 0.68, P < 0.0001 respectively). Percent cob damage was positively correlated to tunnel length, number of holes and borers per plant (r = 0.33, P < 0.0001, r = 0.21, P < 0.0001 and r = 0.69, P < 0.0001, respectively). Percent internode damage was also positively correlated with borers per plant (r = 0.42, P < 0.0001). In 2004, borer density per plant and infestation of Napier grass was very low (data not shown). However, in 2005 we recorded 67.5 and 15.0% plant and tiller infestation, respectively. On Napier we also recorded few *B. fusca* that were 1–2 larval stage.

4. Discussion and conclusions

In the intercropping experiments, with exception of the Mieso site, stem borer infestations were too low to be affected by the non-host haricot bean in the system. In Mieso, borer damage and density decreased with the increase of the proportion of bean in the intercrop. Similarly, Chabi-Olaye et al. (2005a) in mixed cropping trials involving maize, cowpea (*Vigna unguiculata* (L.) Walp.), soybean (*Glycine max* (L.) Merr.) or cassava (*Manihot esculenta* (Crantz)). Schulthess et al. (2004) in a maize–cassava relay crop showed that the advantage of mixed cropping in reducing stem borer densities is more visible at high pest pressure. Furthermore, Schulthess et al. (2004) found that while yields increased in monocropped insecticide-treated maize under low pest pressure, borer densities were similar in both untreated mono- and intercropped maize. The authors concluded that the benefit of reduced pest densities in the maize–cassava intercrop equaled the negative effect of inter-specific plant competition; as a result, the benefits of mixed cropping decreased with a decrease of pest infestations. This is corroborated in the present study by the highest LER, which was calculated for Mieso where pest densities were highest. In the present trials the LERs were mostly >1 indicating that the land use efficiency was higher in inter- than monocrops but it tended to decrease with an increase of maize in the mixed cropping system. Supporting our findings, Amoako-Atta et al. (1983) obtained the highest LER of 1.45 with a maize–cowpea–sorghum mixture and a LER of 1.3 with sorghum–cowpea. Chabi-Olaye et al. (2005a) also consistently obtained LER values greater than those with lowest values of 1–1.35 for maize–soybean. Thus, in the same range as the maize–haricot bean crop, and highest of greater than 1.5 with maize–cassava mixtures. In most of the cases, yield per plant was higher in monocropping systems both in maize and haricot bean compared to intercropped plots indicating the existence of interspecific competition between the two crops. However, there was no significant difference between treatments in plant height, diameter and stand of the maize plants at harvest.

Lower stem borer densities in diversified systems were the result of decreased host finding of ovipositing female moths and the migrating young larvae; first larval instars of both *B. fusca* and *C. partellus* migrate to the whorl of maize or sorghum where they feed on the leaves or disperse to other plants by 'ballooning' (Kaufmann, 1983; Schulthess et al., 2004; Chabi-Olaye et al., 2005b). Thus, the presence of a non-host in the system reduces the chances of the dispersing larvae to land on a suitable host thereby increasing larval mortality. Generally borer parasitism was higher in the maize–haricot bean intercropping system than the monocrop even though it was not statistically significant. Corroborating our findings, Getu (2002) found that at Melkassa no significant difference was observed in terms of percent parasitism between monocrop and intercropping of maize with haricot bean. Although the level of borer parasitism, especially at Mieso was high, the level of infestation was still too high. Getu (personal communication) suggested that the parasitoids come late after the maize or sorghum is already infested at higher level and it may be necessary to conduct ecological studies as to how to build up parasitoid populations at the beginning of the cropping season. Our study also indicated that there is a good potential to control stem borers with parasitoids like *C. flavipes*, especially in Mieso area, if efforts are made to improve situations that favor the parasitoid population. The present studies showed that mixed cropping systems have economic advantages even under low pest pressure. Hence, farmers in the Central Rift Valley of Ethiopia can get an economic advantage by intercropping haricot bean with maize at the ratio of 1:1 to 2:1 as indicated by higher LER values and overall farm income instead of monocropping of both crops.

As it is true for the intercropping experiment at Melkassa, levels of infestation in Western Ethiopia (at Sibu-Sire) were also very low making it difficult to find significant differences between treatments in terms of stem borer damage parameters and yield. However in 2005, a higher level of infestation and leaf feeding score was recorded in the control than push–pull plots. Infestation on Napier grass was also higher in 2005 than in 2004. This may be due to better infestation of stem borers in the latter season than in 2004. Yield per plant and percent cob damage was negatively correlated with percent stem tunneling and borer density per plant, indicating that these parameters are important in measuring impact of stem borer damage on yield and yield parameters. However, Chabi-Olaye et al. (2005b) indicated that the proportion of stem tunneling is more reliable indicator of yield loss due to a number of different pests. This was also true in our intercropping experiment where yield was correlated with stem tunneling but not with other insect damage parameters. Borer density per maize plant was very low and did not differ between treatments. Ndemah et al. (2002) also reported no significant difference between pure maize stands and maize surrounded by grasses in terms of borer density and yield.

Establishment of Napier grass and Desmodium differed depending on soil pH and good establishment was obtained at higher pHs than at lower pHs. Yield per plot varied accordingly and the highest yields were obtained from plots with good establishment of Napier and Desmodium and a high pH. There was no significant difference in the mean pH between plots with only maize and those with Napier and Desmodium, indicating that Desmodium did not play a part in amending the soil pH. From the soil analysis it is clear that in order to increase yield of maize in Sibu-Sire areas (Western Ethiopia) where maize is the major food crop, it is necessary to amend the soil pH instead of applying urea and DAP fertilizers every year using blanket recommendations.

In conclusion, intercropping of maize with haricot bean was advantageous compared to monocropping of either crop. Even though it was not possible to see clear differences between treatments in controlling stem borers, the use of Napier grass and Desmodium for animal feed and the consideration that Desmodium is an important plant for erosion control by farmers in west Wollega areas may contribute for the acceptance of the technology by the farmers. They have also the extra advantage of animal feed from the Napier and Desmodium since they have obtained the same amount of maize yield from the push–pull and control plots where the area covered by maize in the push–pull plots was 15% less than in the control plots. Moreover, the technology can work better in high stem borer infestation areas like Mieso where we have observed Napier plants surrounding sorghum were heavily damaged by stem borers.

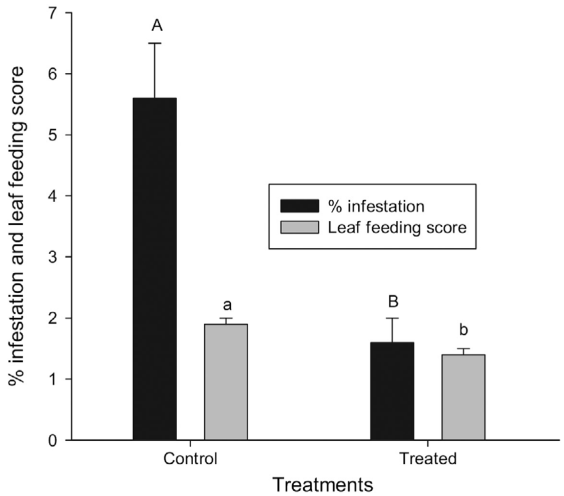

Fig. 1. Mean percent infestation and leaf feeding score in maize with Napier grass (N) and greenleaf Desmodium (D) (treated) and maize pure stand (control) at Sibu-Sire during the 2005 cropping season. Means for the same parameter with different small or capital letter are significantly different from each other (SNK, $P = 0.05$).

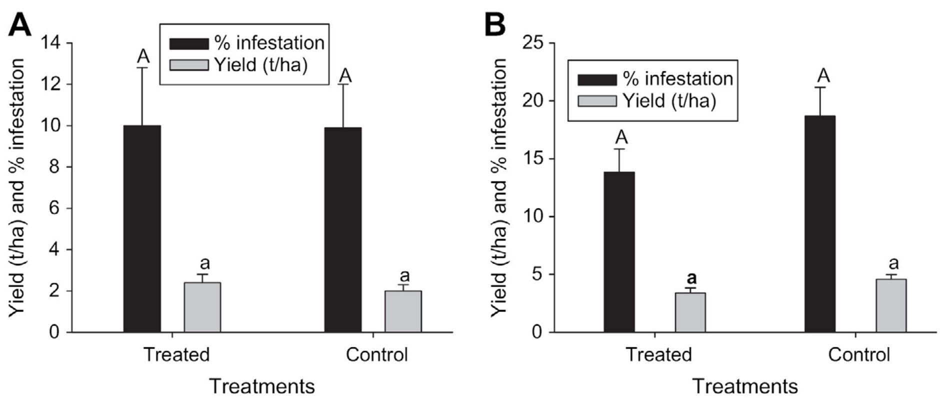

Fig. 2. Mean yield (*t*/ha) and percent infestation in maize with Napier grass (N) and greenleaf Desmodium (D) (treated) and maize pure stand (control) at Sibu-Sire during the 2004 (A) and 2005 (B) cropping season. Means for the same parameter with same small or capital letter for same graph are not different (SNK, $P = 0.05$).

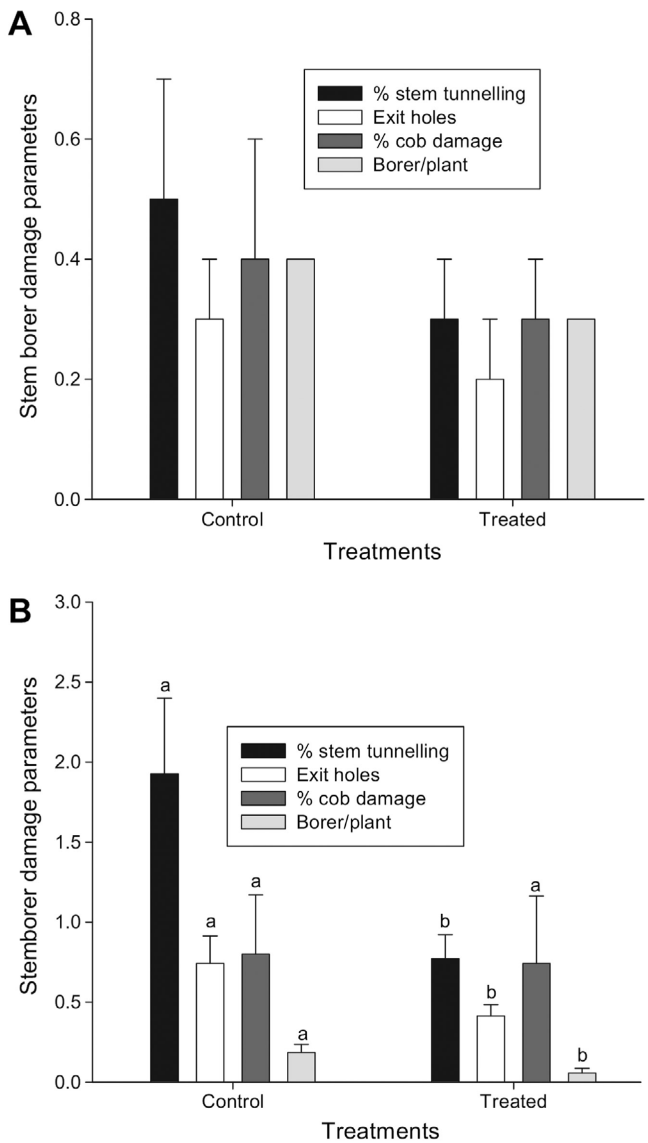

Fig. 3. Mean percent stem tunneling, exit holes, percent cob damage, and borer/plant in maize fields with pure maize (control) or maize with Napier grass and Desmodium (treated) in 2004 (A) and 2005 (B) cropping season at Sibu-Sire. No significant difference between treatments in 2004 and in 2005. Means for the same parameter with different letter are significantly different from each other (SNK, $P = 0.05$).

Table 1. Percent infestation and leaf feeding score by stem borers during the vegetative stage on maize only plots (M) and maize intercropped with haricot bean (HB) planted at different ratios.

	Days after emergence of maize											
	% Infestation						*Leaf feeding score*					
	18		*40*		*60*		*18*		*40*		*60*	
Treatment	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*
2004 Cropping season at Melkassa												
1M:1HB	13.9	2.5	17.7	1.6	35.7	2.3	4.3	0.6	5.0ab	0.5	5.0	0.5
2M:1HB	13.0	0.8	19.4	1.7	35.2	4.1	4.3	0.3	4.6ab	0.6	5.0	0.5
3M:1HB	15.6	4.8	17.1	4.7	42.7	6.0	4.4	1.0	5.3a	0.3	5.3	0.3
4M:1HB	9.8	1.2	10.2	1.6	33.8	6.9	3.3	0.3	3.6b	0.3	4.6	0.8
Maize only	13.7	3.8	13.2	5.2	32.9	3.0	4.5	0.5	4.4ab	1.0	4.5	0.5
2005 Cropping seasons at Melkassa												
1M:1HB	5.2	6.6	6.0	5.4	4.3	5.4	2.6	0.6	3.0	1.0	4.0	0.5
2M:1HB	6.1	1.7	8.6	2.6	9.8	1.6	2.6	0.3	3.3	0.3	0.5	0.3
3M:1HB	2.2	0.3	5.4	0.8	6.3	1.4	2.0	0.0	2.3	0.3	2.6	0.3
4M:1HB	4.4	0.9	6.2	1.5	6.7	2.3	2.0	0.0	2.6	0.3	2.6	0.3
Maize only	3.9	1.0	9.2	3.6	8.4	1.2	3.0	0.5	2.3	0.3	2.6	0.3
2005 Cropping seasons at Mieso												
1M:1HB	98.5b	0.5	64.7	4.0	43.7b	1.2	5.0c	0.0	5.0	0.5	3.5b	0.5
2M:1HB	99.2b	0.2	70.8	4.8	45.7b	2.3	6.0b	0.0	4.0	0.0	3.3b	0.3
3M:1HB	99.4ab	0.3	73.7	3.4	48.9b	1.3	5.6b	0.3	5.0	0.5	4.0b	0.0
4M:1HB	100.0a	0.0	74.1	1.6	47.9b	1.4	6.0b	0.0	4.0	0.0	3.3b	0.3
Maize only	100.0a	0.0	74.8	3.6	61.0b	2.0	7.0c	0.0	5.3	0.6	5.3a	0.3

Means within a column for the same season followed by different letters are significantly different from each other (SNK, P = 0.05).

Table 2. Borer density/plant and borer parasitism (mean± SE) at grain filling stage of maize at Melkassa (2004 and 2005) and Mieso (2005).

	Melkassa (2004)				*Melkassa (2005)*				*Mieso (2005)*			
	Borer/plant		*% Parasitism*		*Borer/plant*		*% Parasitism*		*Borer/plant*		*% Parasitism*	
Treatment	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*
1M:1HB	2.8	0.1	8.0	4.6	1.0	0.5	39.0	9.0	1.7	1.2	100.0	0.0
2M:1HB	1.9	0.1	12.5	4.0	0.3	0.3	40.0	5.7	2.0	1.1	100.0	0.0
3M:1HB	2.0	0.1	13.1	6.2	2.0	0.5	33.3	8.8	4.7	0.3	75.0	25.0
4M:1HB	2.5	0.2	3.2	1.7	0.7	0.6	33.3	3.3	4.7	1.8	75.0	14.4
Maize only	2.2	0.0	0.0	0.0	0.7	0.3	20.0	5.7	3.7	1.3	40.0	40.0

There was no significant difference between treatments for all parameters at both locations (SNK, P = 0.05).

Table 3. Mean (±SE) insect damage parameters and yield of sole maize (M) and maize intercropping with haricot bean (HB) planted at different ratios at Melkassa during harvest in 2004 and 2005 cropping season and at Mieso (2005).

	% Internode damage		*Exit holes*		*% Tunneling*		*% Cob damage*		*% Infestation*		*Borer/plant*		*Yield/plant (g)*	
Treatment	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*
2004 Cropping season at Melkassa														
1M:1HB	14.0	5.3	0.9	0.4	1.5	0.8	7.5	2.4	25.2	0.9	0.2	0.1	74.2	5.4
2M:1HB	25.8	5.5	1.5	0.2	4.3	2.1	11.0	1.5	31.6	0.8	0.7	0.3	90.2	0.8
3M:1HB	26.0	15.0	2.4	1.2	2.9	1.9	6.7	6.7	29.7	5.8	0.5	0.3	83.8	2.2
4M:1HB	20.0	8.1	1.3	0.5	2.9	1.4	7.0	3.6	21.4	2.1	0.7	0.4	81.9	9.7
Maize only	24.8	5.3	2.0	0.7	2.9	0.9	11.9	6.4	28.3	2.9	0.3	0.1	92.8	4.4
2005 Cropping season at Melkassa														
1M:1HB	14.1	1.3	2.8	0.6	0.3	0.1	0.4	0.1	2.0	0.5	0.3	0.3	96.2	0.3
2M:1HB	12.9	2.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.8	0.0	0.0	82.2	1.9
3M:1HB	11.9	0.6	0.6	0.6	0.2	0.2	0.1	0.1	1.3	0.8	0.0	0.0	92.7	14.4
4M:1HB	12.4	2.4	2.8	0.7	0.3	0.1	0.2	0.0	1.7	0.8	0.0	0.0	75.5	12.2
Maize only	16.3	1.9	3.1	3.1	0.5	0.4	0.7	0.6	2.0	1.1	0.3	0.3	96.7	5.8
2005 Cropping season at Mieso														
1M:1HB	11.2b	0.8	2.1ab	0.7	3.9ab	1.7	6.3	0.9	52.0b	0.5b	1.0b	0.0	68.9b	2.6
2M:1HB	6.8b	2.5	1.6b	0.7	2.1b	1.0	10.8	4.2	50.5b	4.8b	1.0b	0.6	67.0b	10.2
3M:1HB	14.1ab	5.2	2.7ab	0.9	4.6ab	2.4	12.6	5.7	56.9ab	0.5ab	3.3ab	1.2	69.5ab	9.4
4M:1HB	12.1ab	1.3	2.7ab	0.7	3.9ab	0.4	5.8	1.7	54.4ab	4.7ab	3.7a	0.7	76.1ab	6.7
Maize only	23.8	2.1	4.0a	0.2	6.8a	1.3	5.7	0.9	62.8a	3.7a	5.7	1.2	94.9a	7.3

Means within a column followed by the same lower case letter for the same year and location were not significantly different at P = 0.05 (SNK).

Table 4. Land equivalent ratio of maize (M) intercropping with haricot bean (HB) planted at different M:HB ratios at Melkassa and Mieso.

Treatment	*Yield/plot (kg)* *M*	*HB*	*LER*	*Value/ha (Eth. birr)*
2004 Cropping season at Melkassa				
1M:1HB	10.4	1.2	1.1	4800
2M:1HB	12.8	0.6	1.1	5566
3M:1HB	12.2	0.4	1.1	5238
4M:1HB	10.5	0.2	0.9	4452
Maize only	12.2	–		5083
Haricot bean only	–	5.8		2255
2005 Cropping season at Melkassa				
1M:1HB	20.1	2.9	1.6	9502
2M:1HB	16.4	0.9	1.1	7183
3M:1HB	17.5	0.6	1.2	7525
4M:1HB	15.5	0.4	1.0	6613
Maize only	16.1	–		6708
Haricot bean only	–	8.5		3305
2005 Cropping season at Mieso				
1M:1HB	7.3	1.6	1.5	3663
2M:1HB	8.5	1.1	1.4	3969
3M:1HB	8.3	0.7	1.3	3730
4M:1HB	8.8	0.6	1.3	3730
Maize only	8.6	–		3583
Haricot bean only	–	2.4		933

M = rows of Maize, HB = rows of Haricot bean

Table 5. Mean (±SE) yield, insect damage parameters and soil pH between plots with maize pure stand and maize with Napier and Desmodium within and between poor and good establishment of the push–pull plants.

	Good establishment of Napier and Desmodium				*Poor establishment of Napier and Desmodium*			
	Treated		*Control*		*Treated*		*Control*	
Parameters	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*	$\bar{X}$	*SE*
Yield (t/ha)	5.2a	0.6	4.6a	0.4	2.20b	0.4	2.40b	0.2
% Infestation	10.4a	2.6	8.9a	2.9	9.50b	2.2	11.3a	12.9
Yield/plant (kg)	0.15a	0.0	0.15a	0.0	0.12b	0.0	0.14a	0.0
% Stem tunneling	0.32a	0.2	0.46a	0.2	0.26a	0.2	0.67a	0.3
Holes/plant	0.31a	0.2	0.26a	0.1	0.08a	0.1	0.23a	0.1
% Cob damage	0.25a	0.2	0.18a	0.1	0.36a	0.2	0.67a	0.4
Borer/plant	0.07ab	0.0	0.03b	0.1	0.10ab	0.1	0.18a	0.1
pH level	5.31a	0.1	5.40a	5.2	5.04ab	0.1	4.93a	0.1

Means within a row for the same Napier and Desmodium establishment group (good or poor) followed by different letters are significantly different from each other (SNK, P = 0.05).

Table 6. Linear regression parameters between establishment score for Napier grass and Desmodium, soil pH and phosphorus (P) and per ha yield of maize in PP trials in Ethiopia during 2004 and 2005. Y = a + bx, where, y = the responses variable, a = intercept, b = slope, x = independent variable (factor).

	a	*b*	*t*	*P*	R^2
y = establishment score for Napier grass and Desmodium, x = soil pH					
2004	–1.23	1.14	7.3	0.0007	0.95
2005	–0.33	0.94	1.05	0.34	0.19
y = establishment score for Napier grass and Desmodium, x = soil phosphorus					
2004	0.42	0.42	1.66	0.16	0.36
2005	0.41	0.39	2.80	0.038	0.69
y = yield t/ha, x = soil pH					
2004	–3.12	1.99	2.76	0.022	0.50
2005	–7.23	3.56	6.55	0.0006	0.84
y = yield t/ha, x = establishment score for Napier grass and Desmodium					
2004	1.13	0.29	4.81	0.0001	1.00
2005	1.15	0.29	3.10	0.027	1.00

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