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Combined control of *Striga hermonthica* and stemborers by maize–*Desmodium* spp. intercrops

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Abstract

The African witchweed (*Striga* spp.) and lepidopteran stemborers are two major biotic constraints to the efficient production of maize in sub-Saharan Africa. Previous studies had shown the value of intercropping maize with *Desmodium uncinatum* in the control of both pests. The current study was conducted to assess the potential role of other *Desmodium* spp., adapted to different agro-ecologies, in combined control of both pests in Kenya. Treatments consisted of intercropped plots of a *Striga hermonthica*- and stemborer-susceptible maize variety and one *Desmodium* sp. or cowpea, with a maize monocrop plot included as a control. *S. hermonthica* counts and stemborer damage to maize plants were significantly reduced in maize–desmodium intercrops (by up to 99.2% and 74.7%, respectively) than in a maize monocrop and a maize–cowpea intercrop. Similarly, maize plant height and grain yields were significantly higher (by up to 103.2% and 511.1%, respectively) in maize–desmodium intercrops than in maize monocrops or maize–cowpea intercrops. These results confirmed earlier findings that intercropping maize with *D. uncinatum* effectively suppressed *S. hermonthica* and stemborer infestations in maize resulting in higher crop yields. They also demonstrate that the other *Desmodium* spp. assessed in the current study have similar effects as *D. uncinatum*, indicating comparable phytochemical and other relevant attributes in these species. Overall results indicate the suitability of the *Desmodium* spp. for the control of both *S. hermonthica* and stemborers in maize.

Keywords: Intercropping; Maize; Desmodium; Cowpea; *Striga*; Stemborer; Control

1. Introduction

Maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* Moench) are the most important cereal crops for most of sub-Saharan Africa. Parasitic plants, the witchweeds (*Striga* spp.), and lepidopterous stemborers, mainly *Chilo partellus* (Swinhoe) (Crambidae) and *Busseola fusca* (Füller) (Noctuidae), are serious biotic constraints to cereal production in the continent and, together, can completely destroy the yield of such crops in the region (Berner et al., 1996; Khan et al., 2000).

The witchweeds, *Striga* spp. (Scrophulariaceae), infest 40% of arable land in the African savanna region, causing annual losses of $7 to $13 billion and threaten indirectly the lives of over 100 million people in the region (Lagoke et al., 1991). Among the 23 species of *Striga* prevalent in Africa, *Striga hermonthica* is the most socio-economically important in eastern Africa (Emechebe and Ahonsi, 2003; Gressel et al., 2004). In Kenya, this weed is a serious constraint to cereal production in the Lake Victoria basin, the coastal strip of Coast Province, and some parts of western Province. The problem is more widespread and serious in areas where both soil fertility and rainfall are low (Khan et al., 2001; Oswald, 2005). *Striga* infestation continues to extend to new areas as farmers abandon heavily infested fields for new ones (Khan, 2002; Gressel et al., 2004).

Striga spp. are obligate root parasites that inhibit host growth via two processes, competition for nutrients and impairment of photosynthesis (Joel, 2000). Such stress can modify the nutritional value of the plant to herbivores and

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its ability to tolerate insect attack (Bukovinszky et al., 2004).

Recommended control methods to reduce *Striga* infestation include heavy application of nitrogen fertilizer, as suggested by Igbinosa et al. (1996), crop rotation (Oswald and Ransom, 2001), use of trap crops susceptible to parasitism by *Striga* such as legumes (Gbèhounou and Adango, 2003), chemical stimulants (Worsham et al., 1959) to abort seed germination, hoeing and hand-pulling (Ransom, 1996), herbicide application (Oswald, 2005), and use of resistant/tolerant crop varieties (Showemimo et al., 2002). All these are limited by the reluctance of farmers to accept them for both biological and socio-economic reasons (Lagoke et al., 1991; Gbèhounou and Adango, 2003). However, if plants antagonistic to *Striga* infestation of maize could be identified beyond those currently known to give only weak control (Oswald, 2005), an appropriate cultural method of *Striga* management could be developed. The most recent technology for controlling *Striga* through impazyr herbicide-resistant mutant maize (IR maize) has shown significant increase in maize yields (Kanampiu et al., 2003). However, the success of IR maize will depend on how widely it is adopted by resource-poor farmers in *Striga*-infested areas. Moreover, it does not address the problem of stemborers, which are a major constraint in cereal farming in the region.

C. partellus and *B. fusca* are the most important cereal stemborers in sub-Saharan Africa where they attack maize and sorghum throughout their growth stages, causing 20–80% grain yield losses (Khan et al., 1997a). Several insecticides are recommended for control of these pests by the national agricultural research systems in Africa but are mainly used by commercial farmers (Van den Berg and Nur, 1998). They are largely beyond the reach of the resource-poor farmers in sub-Saharan Africa in economic terms. Additionally, the mode of application of these chemicals is unhealthy and dangerous. To this end, a joint venture between the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI), has been involved in the development of transgenic (Bt) maize expressing *Cry* genes for the control of maize stemborers since 1996 (Mugo et al., 2001). It is expected that upon commercial release, the cultivars will effectively address the stemborer menace. However, there is an urgent need to develop control strategies that would provide solutions to both stemborer and *Striga* problems that are tailored to the diversity of African cropping systems and are within the reach of the resource-limited small-scale African farmers.

One approach to effective control of the stemborers is the development of control systems using ‘push–pull’ strategies, whereby insect pests are repelled from an intercrop of the main/harvestable crop and a repellent plant, and are simultaneously attracted to a discard/trap crop away from the intercrop stand (Khan et al., 1997b, 2000, 2001; Khan and Pickett, 2004). Various trap and repellent plants have been identified and have been shown to be effective in substantially reducing infestations of stemborers in cereal crops in such ‘push–pull’ arrangements (Khan et al., 1997a, b, 2000). Of the repellent plants, the fodder legume, *Desmodium uncinatum* (Jacq.), was among those that were selected for more extensive field trials. Unexpectedly, in field trials in Suba district of western Kenya, *D. uncinatum* dramatically reduced levels of infestations by *S. hermonthica* when intercropped with maize, with significant increases in maize grain yields compared to maize monocrop (Khan et al., 2000, 2001, 2002). A number of food legumes were similarly tested but none matched the performance of *D. uncinatum* in the suppression of the weed and in increases in maize grain yields (Khan et al., 2002). Although intercropping cereals with food legumes could reduce the number of *Striga* plants that mature in an infested field, cereal crop yields were often significantly reduced in some cases (Oswald et al., 2002).

The specific objective of this study was to investigate whether other *Desmodium* spp., adapted to different agro-ecologies, could offer similar levels of control of stemborers and *S. hermonthica* and enhance comparable grain yields in intercropping arrangements that did not involve any trap crop. They were tested at one agro-ecological zone, where *D. uncinatum* had shown effective control of both pests, in order to have a realistic comparative assessment on their suitability alongside that of *D. uncinatum*.

2. Materials and methods

2.1. Study site

Field trials were conducted during the long rainy seasons (March–August) of 2001–2004 at the International Centre of Insect Physiology and Ecology (ICIPE) Thomas Odhiambo Campus, Mbita Point, in western Kenya, 0°25′S, 34°12′E. It is situated at the eastern shores of Lake Victoria in Suba district of Kenya, where both *S. hermonthica* and stemborers are serious limitations to cultivation of cereals (Watt, 1936). It receives approximately 900 mm of rainfall per annum, has a mean annual temperature of 27 °C, and is located at an altitude of approximately 1200 m above sea level. The field station is infested with *S. hermonthica* (average 100 *S. hermonthica* seeds per 250 g soil). The major stemborer is *C. partellus* (~80%).

2.2. Plot layout and data collection

Maize was intercropped in alternate rows with one of the four species of desmodium (Fabaceae), planted at the onset of the study (March, 2001): silverleaf, *D. uncinatum* (Jacq.) (a medium-high-altitude species); Greenleaf, *D. intortum* (Mill.) (a low-medium-altitude species); Hawaiian tick-trefoil, *D. sandwicense* (Meyer) (a low-medium-altitude species) and pringlei, *D. pringlei* (Watson) (a medium-altitude species) (Skerman et al., 1989); or cowpea (Fabaceae), *Vigna unguiculata* (Walp) (Var. ICV2). Maize was planted at a row-to-row distance of 75 cm and a plant-to-plant distance of 30 cm within the rows, while desmodium was planted through a drilling system in furrows between the rows of maize. A control plot of maize monocrop was included. The six treatments were completely randomised and planted in six replications in a 6 × 6 Latin Square Design (Baily, 1984; Smart et al., 1994). Each treatment plot measured 6 m × 6 m. This design ensured that any uneven stemborer invasion of the crop from one side did not bias the experiment. The maize variety used during 2001–2002 was a stemborer- and *Striga*-susceptible, medium maturity, commercial hybrid 513, recommended for mid-altitude regions with moderate rainfall (Khan et al., 2002). During 2003–2004, another stemborer- and *Striga*-susceptible variety (hybrid 502) was used. Plots were kept weed free by hoe and hand weeding except for *S. hermonthica* throughout the growing season. Additionally, in all plots, 20 kg nitrogen and 50 kg P/ha were applied as diammonium phosphate at planting of maize and 20 kg N/ha was applied as calcium ammonium nitrate as top dressing 6 weeks later. Stemborer infestation levels were assessed nondestructively (once in a cropping season), at 10 weeks after plant emergence, by randomly selecting 63 maize plants in each treatment plot and counting the number of plants with characteristic 'window-paned' and 'pin-holed' leaves and dead-hearts arising from stemborer larval feeding (Ampofo, 1986). This damage was then expressed as a percentage. Similarly, the number of emerged *S. hermonthica* plants was counted from the 63 plants during the same sampling occasion. At full physiological maturity, height of each of 63 maize plants was measured. All the maize plants in each experimental plot were then harvested and grain yield appropriately converted into tonnes/ha. These data were only collected during the long rainy seasons since in all the years the short rains were often unreliable and the maize crop never developed to full maturity.

2.3. Data analysis

Seasonal data were averaged for each treatment. A one-way analysis of variance (ANOVA) (SAS Institute, 2001) using a generalised linear model was used to test for differences among treatments with regards to *S. hermonthica*, stemborer infestation, plant (maize) height, and grain yields. Because of the high variability observed for the actual *Striga* counts, both within and among treatments, $\log_{10}[n+1]$ transformations of the original data were performed, which stabilised the variance for the analyses. Similarly, the data on plant height and stemborer infestation were subjected to square root and arcsine transformations, respectively, and conformed to the assumptions of ANOVA as indicated by tests of normality in the univariate procedure (SAS Institute, 2001) prior to analysis. Thereafter, Tukey's studentised range test was used to separate the means at $p<0.05$. Untransformed means are presented in tables and figures.

3. Results and discussion

All four desmodium species were equally effective in reducing *S. hermonthica* infestations in all seasons except 2002, when *D. uncinatum* performed better (Table 1). Their performance was also significantly better than cowpea, except in 2004 when infestations of the parasitic weed were relatively low in all experimental plots including the maize monocrop. Overall, they all significantly reduced the number of emerged *S. hermonthica* relative to maize monocrop and maize–cowpea intercrop (Fig. 1). Similar results were obtained with respect to stemborer infestations (Table 2 and Fig. 1). Mean percentages of stemborer-damaged plants were significantly lower in all maize–desmodium intercrops compared with those in maize–cowpea intercrop or maize monocrop, except in 2004 when stemborer infestations were exceptionally low, and the *D. sandwicense*/maize intercrop in 2003 (Table 2). Moreover, there were comparable beneficiary effects of the four desmodium species reflected in significantly taller maize

Table 1
Average (±SE) number of emerged *Striga* plants in maize planted in sole stands or intercropped with various *Desmodium* spp. or cowpea at 10 weeks after crop emergence

Treatment	Mean *Striga* counts/plot			
	2001	2002	2003	2004
Maize monocrop	165.7 (20.7)a	316.5 (15.4)a	269.5 (97.7)a	47.8 (14.5)a
Maize + *D. pringlei*	3.0 (1.9)b	13.3 (1.0)c	0.7 (0.3)b	3.7 (2.2)b
Maize + *D. intortum*	0.5 (0.3)b	7.5 (0.6)c	0.7 (0.5)b	5.0 (1.8)b
Maize + *D. sandwicense*	3.0 (1.4)b	7.3 (0.7)c	1.5 (0.8)b	6.2 (2.4)b
Maize + *D. uncinatum*	2.2 (2.0)b	2.5 (1.1)d	3.5 (2.0)b	3.2 (0.8)b
Maize + cowpea	145.8 (41.2)a	122.8 (13.5)b	169.5 (64.7)a	19.7 (8.2)ab
F-values	46.5	124.9	38.3	4.56
Significance	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$

Means followed by different letters in a column are significantly different ($p<0.05$) according to Tukey's studentised range test.

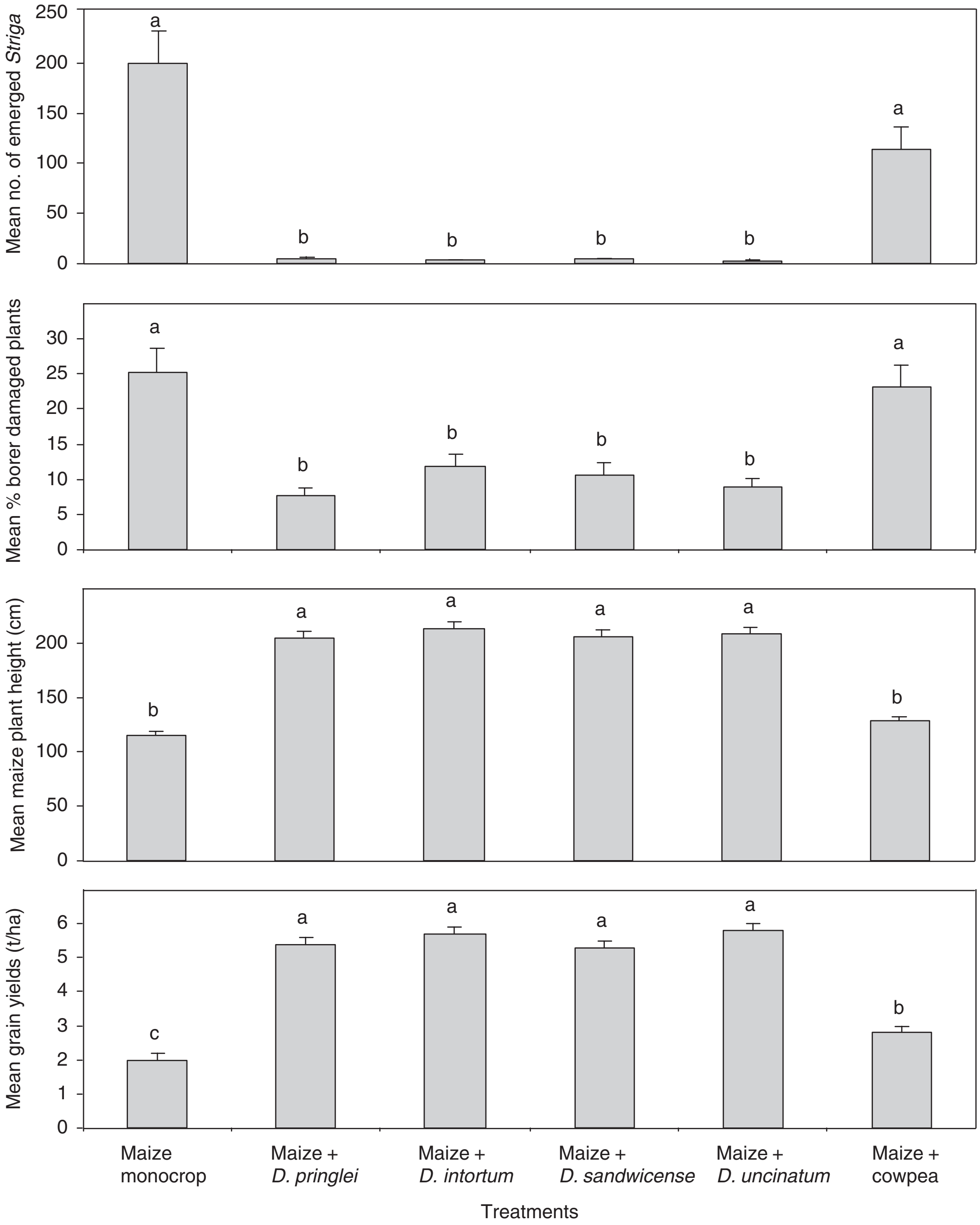

Fig. 1. Average (±SE) number of emerged *Striga* plants, proportion of maize plants damaged by stemborers, height of maize plants (cm) and grain yields (tonnes/ha) per plot in the various intercropping combinations. Means represent data averages over four cropping seasons. Means marked with different letters are significantly different ($p < 0.01$).

plants (Table 3 and Fig. 1) and associated higher grain yields than in maize–cowpea intercrop and maize monocrop (Table 4 and Fig. 1).

These results demonstrate that not just *D. uncinatum* but also other desmodium species efficiently inhibit *S. hermonthica* and suppress stemborers (Khan et al., 2000, 2001, 2002). In a detailed study on the mechanisms of *S. hermonthica* suppression by *D. uncinatum*, Khan et al. (2002) demonstrated that, in addition to benefits derived from increased availability of nitrogen and soil shading, an allelopathic effect of the root exudates of the legume, produced independently of the presence of *S. hermonthica*, is responsible for dramatic reduction of *S. hermonthica* in an intercrop with maize. In a follow-up study, the presence of blends of secondary metabolites with *S. hermonthica* seed germination stimulatory and post-germination inhibitory activities was demonstrated in the root exudates of *D. uncinatum* (Tsanuo et al., 2003), and this combination

Table 2
Mean (±SE) proportions (%) of maize plants with foliar damage caused by stemborers per plot in sole stands or intercropped with various *Desmodium* spp. or cowpea at 10 weeks after crop emergence

Treatment	Mean % maize plants with stemborer damage/plot			
	2001	2002	2003	2004
Maize monocrop	14.2 (1.5)a	38.1 (1.4)a	41.6 (6.9)a	7.2 (1.7)a
Maize + *D. pringlei*	7.8 (1.0)b	10.3 (0.5)c	10.1 (3.8)c	2.6 (0.6)a
Maize + *D. intortum*	5.6 (0.8)b	18.3 (0.7)b	19.3 (2.9)c	4.6 (0.7)a
Maize + *D. sandwicense*	6.5 (1.1)b	9.0 (1.0)c	23.3 (1.3)bc	3.5 (0.9)a
Maize + *D. uncinatum*	6.8 (1.2)b	12.7 (0.6)c	12.2 (4.2)c	3.8 (0.6)a
Maize + cowpea	13.1 (2.0)a	41.0 (0.9)a	31.2 (5.9)ab	7.1 (2.2)a
F-values	7.9	249.3	6.8	2.3
Significance	$p<0.01$	$p<0.01$	$p<0.01$	$p = 0.07$

Means followed by different letters in a column are significantly different ($p<0.05$) according to Tukey's studentised range test.

Table 3
Average (±SE) height (cm) of maize plants per plot at harvest

Treatment	Mean height (cm) of maize plants/plot			
	2001	2002	2003	2004
Maize monocrop	106.4 (9.8)c	117.0 (8.1)b	119.6 (4.0)b	117.1 (6.2)b
Maize + *D. pringlei*	182.5 (3.7)a	191.0 (10.2)a	235.6 (8.2)a	209.9 (4.4)a
Maize + *D. intortum*	208.5 (7.4)a	193.0 (4.0)a	247.5 (3.7)a	206.3 (7.4)a
Maize + *D. sandwicense*	191.7 (7.5)a	181.0 (4.1)a	237.8 (5.5)a	213.6 (16.9)a
Maize + *D. uncinatum*	204.6 (7.7)a	183.2 (1.7)a	239.8 (9.9)a	205.1 (10.6)a
Maize + cowpea	136.5 (5.1)b	117.3 (6.9)b	139.1 (7.1)b	121.3 (1.4)b
F-values	32.30	30.53	79.03	30.66
Significance	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$

Means followed by different letters in a column are significantly different ($p<0.05$) according to Tukey's studentised range test.

Table 4
Average (±SE) grain yield of maize (tonnes/ha) planted in sole stands or intercropped with *Desmodium* spp. or cowpea

Treatment	Mean maize grain yields (tonnes/ha)			
	2001	2002	2003	2004
Maize monocrop	0.7 (0.2)b	1.7 (0.2)c	2.5 (0.2)b	3.2 (0.2)b
Maize + *D. pringlei*	4.5 (0.2)a	5.5 (0.2)a	6.2 (0.7)a	5.2 (0.2)a
Maize + *D. intortum*	5.0 (0.1)a	5.7 (0.1)a	6.2 (0.7)a	5.9 (0.5)a
Maize + *D. sandwicense*	4.5 (0.2)a	5.2 (0.3)a	5.7 (0.5)a	5.7 (0.1)a
Maize + *D. uncinatum*	5.3 (0.2)a	5.3 (0.1)a	6.4 (0.6)a	6.1 (0.4)a
Maize + cowpea	1.5 (0.4)b	3.2 (0.4)b	3.0 (0.4)b	3.5 (0.3)b
F-values	48.1	43.7	17.3	16.7
Significance	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$

Means followed by different letters in a column are significantly different ($p<0.05$) according to Tukey's studentised range test.

provides a novel means of in situ reduction of the *S. hermonthica* seed bank in the soil through efficient suicidal germination even in the presence of graminaceous host plants in the proximity. Likewise, reduced infestation by stemborers in maize–*D. uncinatum* intercrop was earlier shown to be mediated by specific terpenoids present in the volatiles released by the legume (Khan et al., 2000). The performance of the other desmodium species in the present study suggests general similarity in their secondary metabolism with that of *D. uncinatum* and the presence of similar or related chemical constituents in their root exudates and volatiles. The study, therefore, confirms the incremental capability of desmodium species to suppress *S. hermonthica*. We attribute this to the combined effects of germination stimulants and post-germination inhibitors. Our results also show that all the four desmodium species evaluated in the present study outperformed cowpea in reducing infestations of stemborers and in giving healthier and more productive maize.

Desmodium spp. thus increase the options available to farmers that fall in different socio-economic strata, including subsistence farmers, in different agro-ecological zones in tropical Africa, many of whom practice mixed cropping and keep livestock (Khan and Pickett, 2004). To date, different studies have demonstrated the value of intercropping maize with different legume plants for *Striga* control, improved land productivity, and increased gross cash returns (e.g. Khan et al., 2001). Favourable economic returns have been shown to be due to enhanced grain yields as well as incremental value of the legume components. In this regard, *Desmodium* spp. show particular promise as maize intercrops for a combination of different reasons. First, the species evaluated so far are more effective in suppressing *S. hermonthica* than food legumes and also control stemborers. The latter attribute facilitates their use also in 'push–pull' systems for more effective and sustained control of stemborers (Khan et al., 1997a, b, 2001), and from results of the current study (push), it is probable that one of the ways by which desmodium affects stemborer moths is through an indirect mechanism that is yet to be determined. Second, they are very effective nitrogen-fixing legumes with strong nodule development and, therefore, well suited for nitrogen-deficient soils (Whiteman, 1969). For example, *D. uncinatum* can add approximately 110 kg N/ha yr (Henzel et al., 1966), and Suttie (1968) estimated that it contributed approximately 160 kg/ha yr equivalent of nitrogen fertilizer in association with grasses in Kenya. Third, as a nutritious and perennial fodder, farmers are able to obtain quality animal feed throughout the year in situations where household land keeps shrinking due to human population pressures and very little, if any, can be set aside specifically for fodder production (Khan and Pickett, 2004). Finally, in addition to improving animal health and productivity (meat and milk), desmodium fodder and seeds represent valuable commodities with high local demand among different groups of farmers.

In summary, the three desmodium species evaluated in the present study apparently share with *D. uncinatum* the requisite biochemical traits important for a combined control of both *S. hermonthica* and stemborers. Although further studies are required to investigate the nitrogen-fixing capability of *D. sandwicense* and *D. pringlei*, their comparable effect on the health of maize plants and grain yields suggests that they may be equally effective in this regard. These factors, together with the fodder value of these plants, make such intercrops commensurate with small-scale farming in tropical Africa with significant potential for overall improvement in the livelihood of these farmers and their families.

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References

Ampofo, J.K.O., 1986. Maize stalk borer (Lepidoptera: Pyralidae) damage and plant resistance. Environ. Entomol. 15, 1124–1129.

Baily, R.A., 1984. Quasi-complete latin square: construction and randomization. J. Res. Statist. Soc. B 46, 323–334.

Berner, D., Carsky, R., Dashiell, K., Kling, J., Manyong, V., 1996. A land management based approach to integrated *Striga hermonthica* control in sub-Saharan Africa. Outlook Agric. 25, 157–164.

Bukovinszky, Tréfás, H., van Lenteren, J.C., Vet, L.E.M., Fremont, J., 2004. Plant competition in pest-suppressive intercropping systems complicates evaluation of herbivore responses. Agric. Ecosyst. Environ. 102, 185–196.

Emechebe, A.M., Ahonsi, M.O., 2003. Ability of excised root and stem pieces of maize, cowpea and soybean to cause germination of *Striga hermonthica* seeds. Crop Prot. 22, 347–353.

Gbèhounou, G., Adango, E., 2003. Trap crops of *Striga hermonthica*: in vitro identification and effectiveness in situ. Crop Prot. 22, 395–404.

Gressel, J., Hanafi, A., Head, G., Marasas, W., Obilana, A.B., Ochanda, J., Souissi, T., Tzotzos, G., 2004. Major heretofore intractable biotic constraints to African food security that may be amenable to novel biotechnological solutions. Crop Prot. 23, 661–689.

Henzel, E.F., Fergus, I.F., Martin, A.E., 1966. Accumulation of soil nitrogen and carbon under a *Desmodium uncinatum* pasture. Aust. J. Exp. Agric. Anim. Husb. 6, 157–160.

Igbinosa, I., Cardwell, K.F., Okonkwo, S.N.C., 1996. The effect of nitrogen on the growth and development of giant witchweed, *Striga hermonthica* Benth.: effect on cultured germinated seedlings in host absence. Eur. J. Plant Pathol. 102, 77–86.

Joel, D.M., 2000. The long-term approach to parasitic weed control: manipulation of specific developmental mechanisms of the parasite. Crop Prot. 19, 753–758.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K., Gressel, J., 2003. Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls *Striga* spp. and increases yields in several African countries. Crop Prot. 22, 697–706.

Khan, Z.R., 2002. Cover crops. In: Pimentel, D. (Ed.), Encyclopedia of Pest Management. Markel Dekker, Inc., USA, pp. 155–158.

Khan, Z.R., Pickett, J.A., 2004. The 'push–pull' strategy for stemborer management: a case study in exploiting biodiversity and chemical ecology. In: Gurr, G.M., Wratten, S.D., Altieri, M.A. (Eds.), Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods. CABI Publishing, CABI, Wallingford, Oxon, UK, pp. 155–164.

Khan, Z.R., Chilishwa, P., Ampong-Nyarko, K., Smart, L.E., Polaszek, A., Wandera, J., Mulaa, M.A., 1997a. Utilisation of wild gramineous plants for the management of cereal stemborers in Africa. Insect Sci. Appl. 17, 143–150.

Khan, Z.R., Ampong-Nyarko, K., Chilishwa, P., Hassanali, A., Kimani, S., Lwande, W., Overholt, W.A., Pickett, J.A., Smart, L.E., Wadhams, L.J., Woodcock, C.M., 1997b. Intercropping increases parasitism of pests. Nature (London) 388, 631–632.

Khan, Z.R., Pickett, J.A., van den Berg, J., Wadhams, L.J., Woodcock, C.M., 2000. Exploiting chemical ecology and species diversity:

stemborer and *Striga* control for maize and sorghum in Africa. Pest Manage. Sci. 56, 957–962.

Khan, Z.R., Pickett, J.A., Wadhams, L.J., Muyekho, F., 2001. Habitat management strategies for the control of cereal stemborers and *Striga* in maize in Kenya. Insect Sci. Appl. 21, 375–380.

Khan, Z.R., Hassanali, A., Overholt, W., Khamis, T.M., Hooper, A.M., Pickett, A.J., Wadhams, L.J., Woodcock, C.M., 2002. Control of witchweed *Striga hermonthica* by intercropping with *Desmodium* spp., and the mechanism defined as allelopathic. J. Chem. Ecol. 28, 1871–1885.

Lagoke, S.T.O., Parkinson, V., Agunbiade, R.M., 1991. Parasitic weeds and control methods in Africa. In: Kim, S.K. (Ed.), Combating *Striga* in Africa. Proceedings of an International Workshop organized by IITA, ICRISAT and IDRC, 22–24 August 1988. IITA, Ibadan, Nigeria, pp. 3–14.

Mugo, S.N., Bergvinson, D., Hoisington, D., 2001. Options in developing stemborer-resistant maize: CIMMYT's approaches and experiences. Insect Sci. Appl. 21, 409–415.

Oswald, A., 2005. *Striga* control—technologies and their dissemination. Crop Prot. 24, 333–342.

Oswald, A., Ransom, J.K., 2001. *Striga* control and improved farm productivity using crop rotation. Crop Prot. 20, 113–120.

Oswald, A., Ransom, J.K., Kroschel, J., Sauerborn, J., 2002. Intercropping controls *Striga* in maize based farming systems. Crop Prot. 21, 367–374.

Ransom, J.K., 1996. Integrated management of *Striga* spp. in the agriculture of sub-Saharan Africa. In: Proceedings of the Second International Weed Control Congress, Copenhagen, pp. 623–628.

SAS Institute, 2001. SAS User's Guide. Statistics, version 8.2 ed. SAS Institute, Cary, NC.

Showemimo, F.A., Kimbeng, C.A., Alabi, S.O., 2002. Genotypic response of sorghum cultivars to nitrogen fertilization in the control of *Striga hermonthica*. Crop Prot. 21, 867–870.

Skerman, P.J., Cameron, D.G., Riveros, F., 1989. Tropical Forage Legumes, Plant Production and Protection Series No. 2, second ed. Food & Agriculture Organization, p. 692.

Smart, L.E., Blight, M.M., Pickett, J.A., Pye, B.J., 1994. Development of field strategies incorporating semiochemicals for control of the pea and bean weevil, *Sitona lineatus* L. Crop. Prot. 13, 127–135.

Suttie, J.M., 1968. Pasture legume research in Kenya. East Afr. Agric. For. J. 33, 281–285.

Tsanuo, M.K., Hassanali, A., Hooper, A.M., Khan, Z.R., Kaberia, F., Pickett, J.A., Wadhams, L., 2003. Isoflavanones from the allelopathic acqueous root exudates of *Desmodium uncinatum*. Phytochemistry 64, 265–273.

Van den Berg, J., Nur, A.F., 1998. Chemical control. In: Polaszek, A. (Ed.), African Cereal Stemborers: Economic Importance, Taxonomy, Natural Enemies and Control. CAB International, Wallington, Oxon, UK, pp. 319–332.

Watt, W.L., 1936. Control of *Striga* weed in Nyanza Province, Kenya. East Afr. Agric. J., 320–322.

Whiteman, P.C., 1969. The effects of close grazing and cutting on the yield, persistence and nitrogen content of four tropical legumes with Rhodes grass at Samford, southeastern Queensland. Aust. J. Exp. Agric. Anim. Husb. 9, 287–294.

Worsham, A.D., Moreland, D.E., Klingman, G.C., 1959. Stimulation of *Striga asiatica* (witchweed) seed germination by 6-substituted purines. Science 130, 1654–1656.