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The impact of *Desmodium* spp. and cutting regimes on the agronomic and economic performance of *Desmodium*–maize intercropping system in western Kenya

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ABSTRACT

Low soil fertility, stemborers (particularly, *Chilo partellus*) and *Striga* weeds (*Striga hermonthica* and *Striga asiatica*) are major limitations to production of maize in western Kenya. The “Push–Pull” technology (“PPT”) has been described as an appropriate innovative technology capable of addressing these constraints. The technology involves intercropping maize with *Desmodium* and planting Napier grass (*Pennisetum purpureum*) around the intercrop, but in the current study a modified PPT was used and Napier grass was not included. Field trials were conducted in two locations in western Kenya during 4 subsequent seasons to test the hypothesis that maize yield, the degree of *Striga* suppression and economic benefits of intercropping maize with *Desmodium* are affected by: (i) the related biomass production by different *Desmodium* species and (ii) the cutting regime of the *Desmodium*. Maize was intercropped with *Desmodium uncinatum* (Jacq.) DC, cv Silverleaf or *Desmodium intortum* (Mill.) Urb. cv Greenleaf, and treatments with sole maize (with and without urea) were included for comparison. To eliminate phosphorus (P) deficiency, all treatments received basal P. The first two *Desmodium* cutting events were fixed at land preparation i.e. at the start of every season, and 4 weeks later, following the recommended practice, while the third cutting was varied and conducted at 9, 12 or 18 weeks after planting maize. Maize yield in the *Desmodium*–maize intercropping system was only higher than sole maize without urea from the third season. This implies that when P is not limiting inclusion of *Desmodium* spp. into the maize cropping system would provide a substitute for inorganic N fertilizers to enhance crop growth and yield after *Desmodium* becomes well established. Cumulative maize grain yield over the four seasons with the *D. intortum* and *D. uncinatum* intercrops were 6.3 and 7.0, and 10.9 and 11.6 t ha^{−1} in Busia and Siaya, respectively, and significantly higher than or comparable to a maize monocrop (5.8 and 11.8 t ha^{−1}). Average net benefits from *Desmodium* intercropping over the four seasons were increased by 1290 and 918\$ ha^{−1} relative to the maize monocrop in Busia and Siaya, respectively. Biomass yields were significantly higher for *D. intortum* than for *D. uncinatum*. Varying the time of the third *Desmodium* cutting had little effect on *Desmodium* biomass yields or maize grain yields in Busia, while in Siaya, *D. intortum* biomass yields were highest when cut at 12 weeks after planting. In the *Desmodium* intercropping systems, *Striga* counts were reduced by 95% in Busia and by 65–90% in Siaya with higher reductions when *Desmodium* was cut at 18 weeks after planting. In summary, the use of PPT provides robust and high economic benefits to smallholder farmers in western Kenya. The use of *D. uncinatum* with the third cutting at 18 weeks after planting is recommended, but can be modified according to the need for fodder without much effect on maize yield or revenue.

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1. Introduction

Maize (*Zea mays* L.) is an important cereal crop for most of sub-Saharan Africa (Pingali, 2001). Previous studies in western Kenya have shown that low soil fertility (Okalebo et al., 2006), African witchweed (*Striga* spp.), lepidopteran stemborers (*Chilo partellus* Swinhoe) and unreliable rainfall are major causes of low maize yields (De Groote et al., 2010; Odendo et al., 2001). Soil nutrient mining and the resultant soil fertility decline occur in most areas in Kenya, as observed by the negative N, P and K balance at the farm level (Smaling et al., 1997). These nutrient deficits are reflected in the overall low (<1 t ha⁻¹) and declining maize yields (Okalebo et al., 2006). However, survey in Siaya county has shown that yield increases from 0.5–0.7 to 1.4–1.6 t ha⁻¹ can be achieved in western Kenya when improved maize varieties are used and fertilizers are applied (Odendo et al., 2001). The *Striga*-prone area forms a band around Lake Victoria in Western and Nyanza provinces of Kenya (De Groote et al., 2008). *Striga hermonthica* is estimated to infest about 200,000 ha of land and causes crop yield losses varying between 5% and 100% (Hassan et al., 1994; Parker and Riches, 1993). Stem-borers occur in all major agro-ecological zones of Kenya and cause average crop losses of 13.5% countrywide and 16.6% in the Moist Mid-Altitude zone (De Groote et al., 2010).

Over the last two decades, research has provided a sound knowledge base on cropping systems, and crop and land management practices that increase food production while repressing the *Striga* spp. (Kanampiu et al., 2003). These practices consist of the use of one or several components, including the use of herbicide resistant/tolerant maize varieties (i.e. imazapyr resistant (IR) and Kakamega *Striga* Tolerant Population (KSTP)), rotation or intercropping with legumes that trigger suicidal *Striga* germination, application of fertilizer and organic inputs, irrigation and hand pulling (Kanampiu et al., 2003; Khan et al., 2002). Options for replenishing soil fertility and improving crop productivity in western Kenya include the use of mineral fertilizers, organic inputs (or their combination), phosphate rock, short duration fallows, N-fixing grain and forage legumes (Dahlin and Stenberg, 2010; Jama et al., 1997; Kifuko et al., 2007; Ndung'u et al., 2006; Ojiem et al., 2007; Okalebo et al., 2006). In some areas, the adoption of the proposed technologies has been high and positive impact has been reported; but in other areas adoption has been slow and uneven due to various socio-economic and environmental factors (Gachengo et al., 2004; Murage et al., 2011; Okalebo et al., 2006). To improve crop productivity in western Kenya, there is, therefore, need to practice integrated soil fertility management (ISFM) approaches (Vanlauwe et al., 2010); but given that pests significantly reduce cereal production in this region, ISFM can only be effective when used in combination with integrated pest management (IPM) approaches that reduce pest infestation and result in introduction of minimal toxic substances into the environment.

One promising integrated approach that accommodates the principles of ISFM and IPM is the “Push–Pull” technology (PPT) that uses a mixture of behavior-modifying stimuli to manipulate the distribution and abundance of insects. This strategy was established in 1987 as an approach for integrated pest management for control of *Helicoverpa* in cotton crops in Australia. In Kenya, the International Centre of Insect Physiology and Ecology (*icipe*) and partners developed PPT for control of stemborers and *Striga* weed. The technology involves intercropping maize with a stemborer moth-repelling legume, *Desmodium uncinatum* (Jacq.) DC., and planting Napier grass (*Pennisetum purpureum* (L.) Schumach.) around the intercrop, which attracts and traps the stemborer moths (Khan et al., 2000). However, in western Kenya, farmers have adapted the technology differently based on the available resources, land availability and farming systems. Thus, in the instances where land is limiting, soil fertility is of greater concern and stemborer is not a

problem, Napier grass is left out (Farmers, pers comm.). In addition to the N-fixing capacity of *Desmodium* spp., chemicals released by its roots induce abortive germination of *Striga*, providing a measure of control of this noxious weed (Khan et al., 2002; Midega et al., 2010). Nitrogen fixed by the intercrops may be available to the associated cereal crop in the current growing season through direct N transfer (He et al., 2003) or as a residual N for the benefit of the succeeding cereal crops (Baijukya et al., 2006).

Napier grass and *Desmodium* are nutritious fodder/forage crops. *Desmodium* also offers a good cover to the soil that leads to improved soil moisture content and organic matter, and reduced weeds. In integrated crop–livestock systems, lack of quality feed and low dry matter intake are major constraints (Omoro et al., 1996), and so *Desmodium* spp. can provide a highly nutritious fodder supplement. However, farmers may require fodder at different times during the season. But, subjecting *Desmodium* to different cutting regimes could have an impact on crop yields through effects on N fixation, transfer and mineralization, as well as changes in competition for light and nutrients between maize and *Desmodium*. Cutting leys has been shown to increase senescence and turnover of nodules and roots (Jarvis and MacDuff, 1989), and has also been shown to reduce root biomass compared with intact plants (Dahlin and Stenberg, 2010). The PPT has been demonstrated to be effective in controlling stemborers and *Striga* weed with concomitant maize yield increases under farmers' conditions in western Kenya (Khan et al., 2001, 2008a,b), but the effects of the *Desmodium* cutting regime on the performance of the system are not yet fully understood. Also, despite the relatively well-documented role of *D. uncinatum* in controlling cereal pests and increasing maize yields (De Groote et al., 2010; Khan et al., 2006) in western Kenya, little information exists on the more than 300 other *Desmodium* spp. with diverse morphological characteristics. Other *Desmodium* spp., including *Desmodium pringlei*, *Desmodium sandwicense* and *Desmodium intortum*, have shown similar effects as *D. uncinatum* on *Striga* suppression within the “Push–Pull” method (Khan et al., 2007a,b), but unlike *D. uncinatum*, they have not been tested widely in the farmers' fields. *Desmodium* species adapt differently to different environments, which also affects their production potential. Research shows that the quantity of N₂ fixed by the legume in a cereal–legume system depends on the species morphology and the effectiveness of N₂-fixing bacteria (Ofori and Stern, 1987). It is, therefore, of interest to evaluate the performance of PPT using a *Desmodium* species with a higher biomass yield potential such as *D. intortum* (Luck, 1972).

The objectives of this study were therefore to: (i) assess maize grain and *Desmodium* fodder yield in a *Desmodium*–maize intercropping system using two *Desmodium* spp.—*D. uncinatum* and *D. intortum*; (ii) assess how varying the *Desmodium* cutting regime impacts on maize production and *Striga* incidence and (iii) determine the economic viability of the different *Desmodium* spp. and cutting regimes.

2. Materials and methods

2.1. Study area

The study was conducted in western Kenya for two years (2009 and 2010). The area is densely populated with about 360 inhabitants km⁻² (De Groote et al., 2008) and a large proportion of poor people (Central Bureau of Statistics, 2003). Most households predominantly grow maize on small land holdings and obtain average yields of about 1 t ha⁻¹ (Odendo et al., 2001). The main cash crops are cotton and sugarcane, but horticulture and dairy farming are becoming increasingly important as cash income sources (De Groote et al., 2010). The experiments were installed in two fields

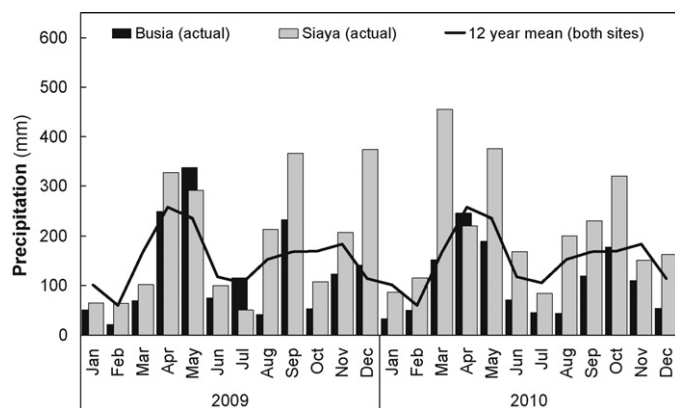


Fig. 1. Monthly rainfall during the study period and twelve-year mean rainfall from the study sites.

of smallholder farmers in Nyabeda location, Siaya County ($0^{\circ} 39.5' N$, $34^{\circ} 1.5' E$, 1273 masl), and Matayos location, Busia County ($0^{\circ} 26.1' N$, $34^{\circ} 52.2' E$, 1182 masl). Busia and Siaya counties cover an area of 1262 and 1520 km², respectively. Altitudes range between 1130–1375 m and 1140–1400 m in Busia and Siaya, respectively, with a mean annual temperature of 21–22 °C in both counties. Rainfall in western Kenya is bimodal with a long rains (LR) season from March to August and a short rains (SR) season from September to December. Rainfall during the study period was measured using two rain gauges installed in the field in Siaya while rainfall data for Busia were obtained from a nearby meteorological station. During the study period, Busia received 1682 and 1978 mm during year 2009 and 2010, respectively. The corresponding values for Siaya were 1676 and 2114 mm, respectively (Fig. 1). Generally, average rainfall amounts in the Busia site during the study period were below the 12 years mean rainfall amount but the Siaya site received rainfall amounts above the 12 years mean rainfall amount.

The soils are low in natural fertility and classified as Orthic Ferralsol in Busia and Humic Acrisol in Siaya (FAO/UNESCO, 1990). Soil samples were collected at 0–20 cm soil layer. Initial characterization of the study sites showed that the soil in Busia was slightly acidic (pH 5.0) with low total N (0.16%) compared with the soil in Siaya (pH 5.6, total N 0.24%). The soil in Siaya had a deep profile and higher levels of organic carbon (2.51%), exchangeable bases (0.4K, 1.68Mg, 4.93Ca cmol_c kg⁻¹), cation exchange capacity (10 cmol_c kg⁻¹) and clay (38%) relative to the soil in Busia. The corresponding values for Busia were: organic carbon (1.44%), exchangeable bases (0.22K, 0.65Mg, 2.28Ca cmol_c kg⁻¹), cation exchange capacity (6.67 cmol_c kg⁻¹) and clay (28%). Both soils were very low in available P which amounted to 1.94 and 0.70 mg P kg⁻¹ in Busia and Siaya, respectively.

2.2. Experimental design

In both sites, an experiment was started in April 2009 during the long rains season (LR2009). Treatments consisted of three cropping systems, namely: (i) *D. uncinatum* intercropped with maize, (ii) *D. intortum* intercropped with maize, and (iii) a sole maize crop. Maize and *Desmodium* were planted at the same time during the first season. During this season, *Desmodium* was allowed to establish and no cutting of biomass was done. In the subsequent seasons, cutting regimes were imposed in the intercropping systems: The *Desmodium* was cut at land preparation, i.e. at every start of each season, which corresponded to 18, 49 and 69 weeks after trial establishment in the short rainy season of year 2009 (SR2009), and long and short rainy seasons of year 2010, respectively, and again at 4 weeks after planting (WAP) maize, which is recommended for good maize

establishment (Khan, pers. comm.). The third cutting was varied according to the treatment, and done 9, 12 or 18 WAP. In the maize monocropping system, two treatments were imposed, starting in the short rainy season of 2009 (SR2009): (i) a control without urea and (ii) a treatment with urea application. The eight treatments were arranged in a randomized complete block design, replicated three times with plot sizes of 10 m × 10 m.

2.3. Trial management

During the first season (LR2009), basal P and K were applied before planting as triple superphosphate (TSP) and muriate of potash (MOP) at rates of 60 kg P ha⁻¹ and 60 kg K ha⁻¹, respectively. Maize (*Z. mays* L., IR variety) and *Desmodium* spp. were sown in alternating rows at the same time. Maize seeds were sown at a rate of 44,444 plants ha⁻¹ (0.75 m between rows × 0.3 m within the row), and *Desmodium* seeds were sown in drills in between the maize lines at a seed rate of 2.5 kg ha⁻¹. Plots were kept weed-free by hand weeding, and termites and stemborers were controlled by applying commercial insecticides; namely, Gladiator® (active ingredient, bromethalin 0.01%, Nova Industries Ltd., Nairobi) and dilute stemborer dust formulation (active ingredients, pirimiphos methyl 1.62% and pyrethrin 0.31%, Dow Agrosociences LLC, Indianapolis, IN, USA), respectively. In the subsequent seasons, all operations were repeated, apart from planting the *Desmodium* spp., which was instead cut at the ground surface using a cutlass at the prescribed cutting times, and allowed to regrow. Urea was split-applied to the sole maize crop at a rate of 90 kg N ha⁻¹. At 6 WAP when maize had reached knee-height, urea was applied at a rate of 45 kg N ha⁻¹, and 3–4 weeks later. After a rainy event, a subsequent application was done at a rate of 45 kg N ha⁻¹. Maize was harvested at full maturity (about 18 WAP). To assess dry matter yield, maize grain was oven-dried to attain a moisture content of 12.5% while stover was air-dried and dry weights taken. *Desmodium* biomass dry matter yield was determined at each cutting event. *Striga* emergence was determined after the second weeding (around 12 WAP) by counting the emerged *Striga* plants inside each 10 m × 10 m experimental plot containing all the maize plants without removing the *Striga* plants. Data on *Striga* count were converted to counts per square m (m²) and transformed using logarithm transformation (Log₁₀) to improve homogeneity of variance before analysis of variance.

2.4. Economic analysis

A financial analysis using discounted partial budgets was carried out to evaluate and compare the economic returns of producing maize and *Desmodium* under different *Desmodium* cutting regimes. The three economic performance indicators calculated were: (i) net benefits (NB), (ii) benefit: cost ratios (BCR), and (iii) marginal rate of return (MRR). The net benefits calculation of maize–*Desmodium* system was done as follows:

$$NB_i = \frac{(M * P_m + M_s * P_s + D * P_d) - (X_i * P_x)}{\text{discount rate}}$$

where *M* and *D* are the yield per ha of maize and *Desmodium*, respectively, *P_m* is the price of maize, *P_d* is the price of *Desmodium* included in maize–*Desmodium* system, while *P_x* is the price of inputs *X* used in the production of maize and *Desmodium* in the system.

Benefit: cost ratio was computed as the ratio of benefits (value of the products) over costs, while the MRR was computed as the additional benefits obtained from a maize–*Desmodium* system compared to the control. Unit prices of production inputs (*P_x*) and of maize grain (*P_m*), stover (*P_s*) and *Desmodium* fodder (*P_d*) were recorded at local stockists and markets, and averaged over the four seasons (Table 1). Production costs included labor for land

Table 1
Parameters used for the financial analysis of the different cropping systems.

Parameter	Value
Price of urea (USD kg ⁻¹)	0.60
Price of triple superphosphate (TSP) (USD kg ⁻¹)	0.69
Price of IR maize seed (USD kg ⁻¹)	1.88
Price of <i>Desmodium</i> seed (USD kg ⁻¹)	14.1
Labor wage (USD 6 h ⁻¹)	1.76
Maize grain (USD kg ⁻¹)	0.53
Maize dry stover (USD t ⁻¹)	22.1
<i>Desmodium</i> green fodder (USD t ⁻¹)	33.0

1 USD = 85 KES.

preparation, fertilizer application, planting, weeding, *Desmodium* cutting and harvesting of maize, and purchase of farm inputs. Cost of transporting inputs was incorporated in the cost of applying fertilizer. The time taken to perform every activity was recorded and the labor was valued at Kshs 150 (USD 1.76) per working day (6 h). Opportunity costs of capital were taken into account by discounting at 10% per year (5% per season), a rate commonly used in studies involving resource-poor smallholder farmers (Rommelse, 2000).

Net benefits and the benefit: cost ratios were calculated to allow for comparison among different treatments. Technologies are deemed feasible if net benefits are positive. MRR was calculated for comparison between the control and other treatment. In calculating MRR, sole maize control (with no N applied) was used for comparison, and thus MRRs were not calculated for the treatments with N less than or equal to control.

2.5. Statistical analysis

The generated data were subjected to analysis of variance (ANOVA) to determine the effect of cropping systems, intercropped *Desmodium* species and cutting regimes using a mixed linear model (MIXED procedure, SAS Institute Inc., 2003), with the treatments considered as fixed factors, and ‘replicate’ as a random factor, separately for each site. A one-way ANOVA was conducted to evaluate differences between the 8 treatments (6 intercropping systems and 2 sole maize systems), as well as a two-way ANOVA for evaluating the interaction effects between *Desmodium* species and cutting regimes in the 6 treatments with the intercropping systems separately. Treatment differences were evaluated by computing least square means and the standard errors of difference (SED), referred to as SED1 and SED2 for the one-way and two-way ANOVAs, respectively. *Striga* emergence numbers were log-transformed, to produce normally distributed data and improve homogeneity of variance, before analysis of variance. Significance differences were evaluated at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$.

3. Results

3.1. Maize grain and stover yields

The effect of *Desmodium* intercropping and cutting regimes on maize grain and stover yields differed significantly between the seasons and sites (Figs. 2 and 3). In the first season (LR2009), during which the systems were established and cutting regimes and urea application were not yet imposed, average maize grain yields of 1.1 and 1.9 t ha⁻¹ were observed in Busia and Siaya, respectively, while stover yield equaled on average 2.4 t ha⁻¹ in both sites. There was

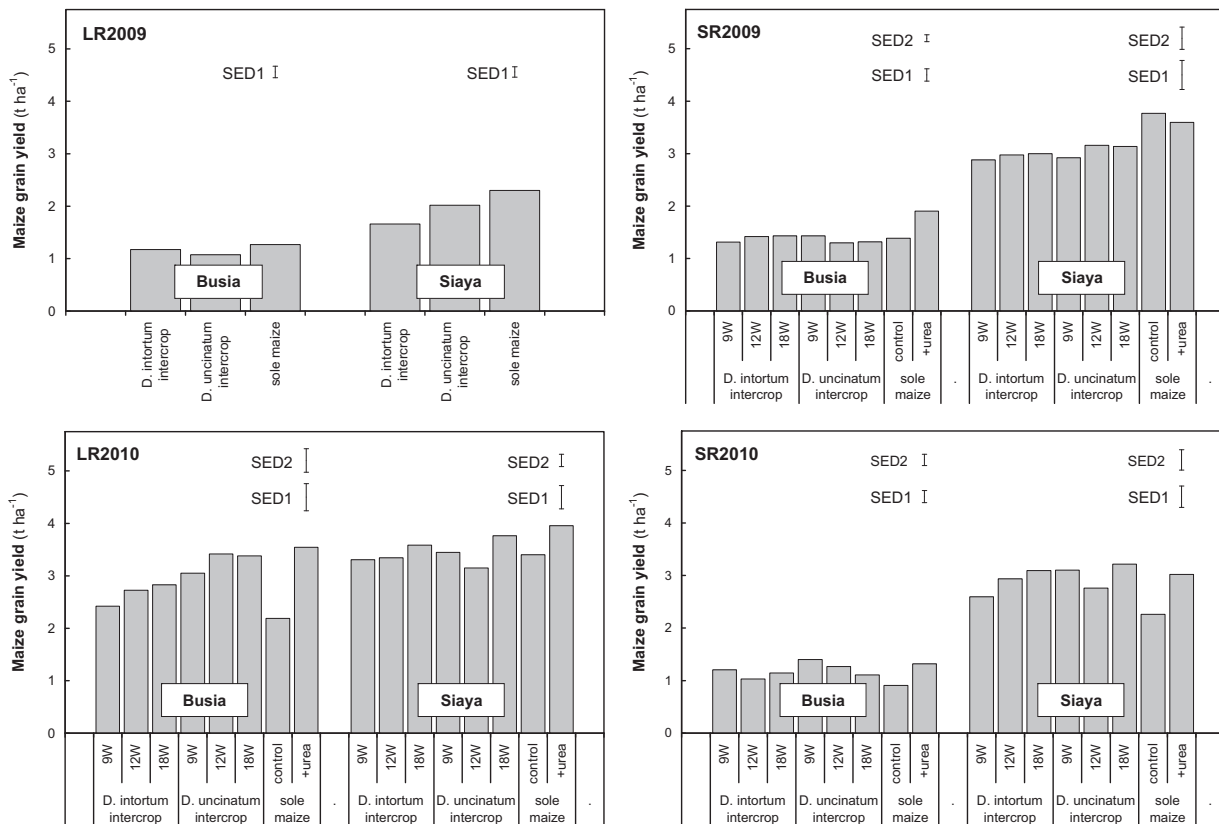


Fig. 2. Maize grain yield from *Desmodium* intercropping systems with two *Desmodium* species and different cutting regimes relative to a sole maize system with or without urea application over 4 subsequent seasons. SED1 and SED2 are standard errors of difference for comparison of all treatments (one-way ANOVA) and for the interaction effect of *Desmodium* species and cutting regime (two-way ANOVA), respectively. W, weeks after planting maize; LR2009 and SR2009, long and short rains seasons of 2009, respectively; LR2010 and SR2010, long and short rains seasons of 2010, respectively.

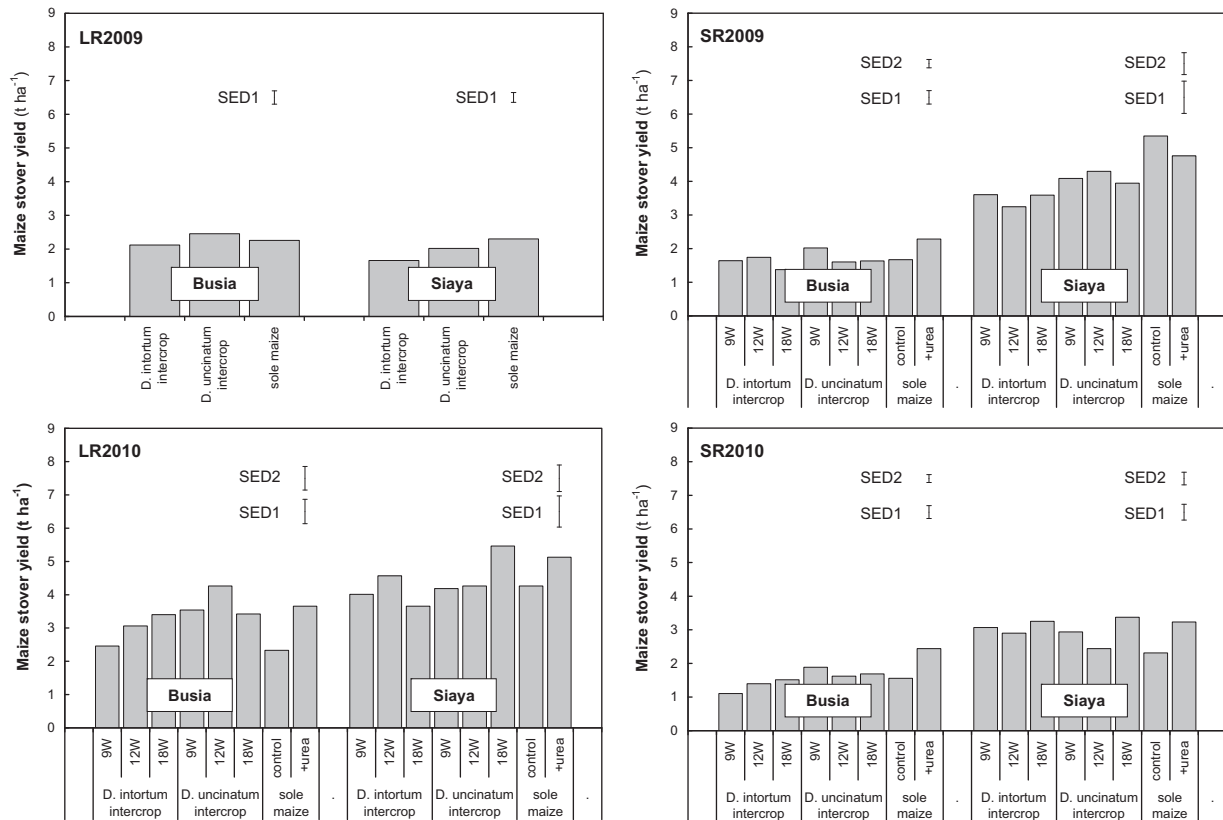


Fig. 3. Maize stover yield from *Desmodium* intercropping systems with two *Desmodium* species and different cutting regimes, relative to a sole maize system with or without urea application, over 4 subsequent seasons. SED1 and SED2, standard errors of difference for comparison of all treatments (one-way ANOVA) and for the interaction effect of *Desmodium* species and cutting regime (two-way ANOVA), respectively; W, weeks after planting maize; LR2009 and SR2009, long and short rains seasons of 2009, respectively; LR2010 and SR2010, long and short rains seasons of 2010, respectively.

no significant maize grain and stover yield difference between sole maize and maize intercropped with the two *Desmodium* species in both sites. During the second season (SR2009), maize grain and stover yields were not affected by *Desmodium* intercropping in Busia, while in Siaya, a significant maize grain and stover yield loss of about 0.8 and 1.6 t ha⁻¹, respectively, was recorded, relative to the sole maize system. *Desmodium* species or cutting regime did not significantly affect maize grain and stover yields in the SR2009 season in any of the two sites. In the long rains season of 2010 (LR2010), grain and stover yields in the intercropping systems were comparable or higher than yields in the sole maize treatment without urea application in both sites. In Busia, maize grain yield in the intercropping system with *D. intortum* (2.7 t ha⁻¹) was significantly lower than with *D. uncinatum* (3.3 t ha⁻¹) but comparable to the yield of the sole maize with urea applied. Maize stover yields from sole maize system with urea applied were comparable with stover yield from intercropping system with *D. uncinatum* (about 3.7 t ha⁻¹), but lower stover yields were obtained from intercropping system with *D. intortum* (3.0 t ha⁻¹). Maize grain and stover yields were not affected by cutting regime in Busia. In Siaya, slight but significant maize grain yield increase was recorded when *Desmodium* was cut at harvest (18 WAP) relative to when the cutting was imposed at 9 or 12 WAP, irrespective of *Desmodium* spp. Generally, higher stover yields were obtained in Siaya (4.4 t ha⁻¹) compared to Busia irrespective of the treatments, but no significant effect of *Desmodium* spp. or cutting regime was observed in the former. In the last season, i.e. short rains season of 2010 (SR2010), average maize grain yield from all treatments in Busia was low (1.2 t ha⁻¹) due to poor rainfall and was not affected by the treatments. Maize stover yields in the *Desmodium* intercropping system were again lower when intercropped with *D. intortum* (1.3 t ha⁻¹) than with *D. uncinatum*

(1.7 t ha⁻¹) and not affected by cutting regimes. In Siaya maize grain yield obtained in *Desmodium* intercropping system was comparable to the yield of the sole maize crop with urea applied. Stover yields were significantly ($P < 0.1$) higher only when *D. uncinatum* was cut at 18 WAP relative to when the cutting was done at 12 WAP, but were not affected by the *Desmodium* species.

In Busia, cumulative maize yields over the 4 seasons were highest for the sole maize crop with urea (8.0 t ha⁻¹), followed by the intercrop with *D. uncinatum* (7.0 t ha⁻¹) (data not shown). Yields were lowest (6.1 t ha⁻¹) in the sole maize crop without urea and the intercrop with *D. intortum*. In Siaya, cumulative maize yield was also lowest for the intercrop with *D. intortum* (10.9 t ha⁻¹) and highest for the sole maize crop with urea applied (12.9 t ha⁻¹). For the intercrop with *D. uncinatum* and the sole maize crop without urea, intermediate cumulative yields were observed (11.7 t ha⁻¹). The cutting regime of the *Desmodium* did not affect maize yields in any of the two sites.

3.2. *Desmodium* biomass yields

During the first season (LR2009), the *Desmodium* was not cut but was allowed to establish. In subsequent seasons, *Desmodium* biomass yield was higher in Siaya than in Busia, irrespective of the *Desmodium* species or cutting regime (Fig. 4). During the SR2009 season, initially (at land preparation and at 4 WAP) no differences in cumulative *Desmodium* biomass yields were observed, but when the third cutting was imposed at 12 or 18 WAP, yields were higher for *D. intortum* than for *D. uncinatum* in both sites. At the start of the LR2010 season, cumulative *Desmodium* biomass yield was higher by 1.8 t ha⁻¹ for *D. intortum* than for *D. uncinatum*, irrespective of the cutting regime in Busia; while in Siaya, biomass yields were higher

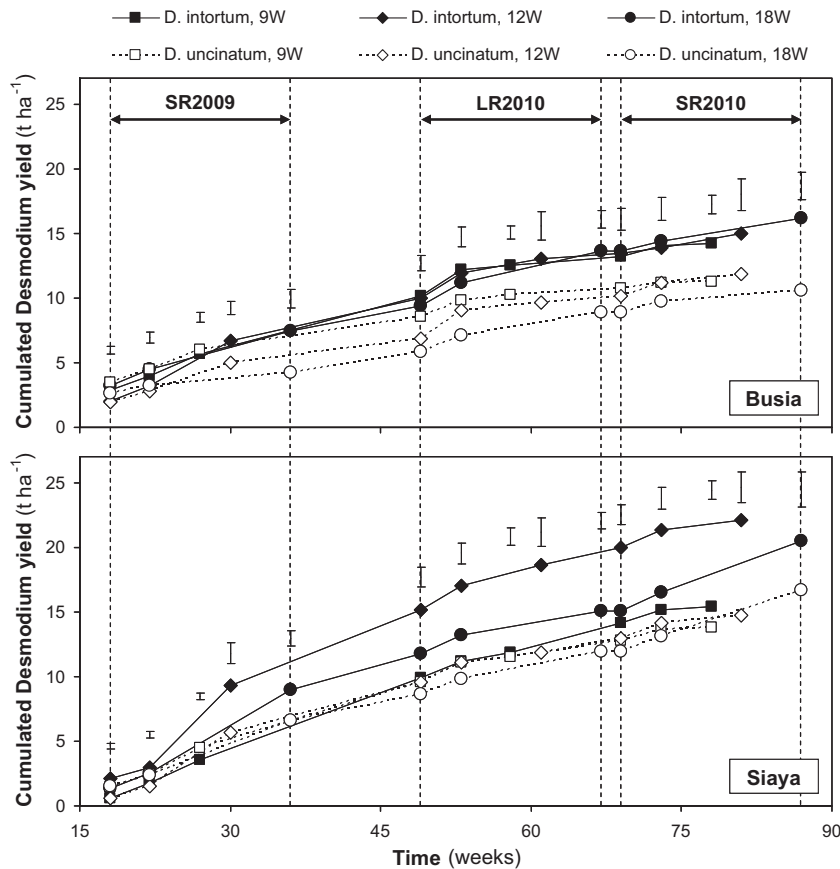


Fig. 4. Cumulative *Desmodium* yield from *Desmodium* intercropping systems with two *Desmodium* species and different cutting regimes. The first two and the last two error bars in each season are SED1 and SED2, respectively. SED1, comparison of all treatments (one-way ANOVA) and SED2, interaction effect of *Desmodium* species and cutting regime (two-way ANOVA); W, weeks after planting maize; LR2009 and SR2009, long and short rains seasons of 2009, respectively; LR2010 and SR2010, long and short rains seasons of y 2010, respectively.

for *D. intortum* only when the third cutting had been done at 12 or 18 WAP in the preceding season. These trends persisted up to the end of the SR2010 season. In Busia, cumulative *Desmodium* biomass yields were unaffected by the cutting regime, and 2.9–5.6 t ha⁻¹ higher for *D. intortum* than for *D. uncinatum*. In Siaya, cumulative biomass yields were 3.8–7.4 t ha⁻¹ higher for *D. intortum* than for *D. uncinatum*, but only if the third cutting was done at 12 or 18 WAP. Significantly high biomass yields were observed for *D. intortum* cut at 12 WAP.

3.3. *Striga* plant counts

During the first season (LR2009), *Striga* plant counts were not affected by intercropping with *Desmodium*, and equaled about 0.3 and 1.6 plants m⁻² in Busia and Siaya, respectively (Fig. 5). In the subsequent season (SR2009), *Striga* counts were similarly not affected by treatments in Busia. In contrast, in Siaya, *Striga* counts equaled 0.8 plants m⁻² for the sole maize crops, while in the intercropping systems, counts equaled 1.2 plant m⁻², independent of *Desmodium* species or cutting regime. In the LR2010, similar trends were observed. *Striga* counts were not affected by treatments in Busia, while in Siaya, *Striga* counts were highest in the sole maize crop without urea application (14.5 plants m⁻²), followed by the sole maize crop with urea application (7.9 plants m⁻²). Intercropping with *Desmodium* reduced *Striga* counts by 76%, irrespective of the species or cutting regime. In the last season, *Striga* counts were highest in the control sole maize system in both sites, followed by the sole maize system with urea application. In Busia, *Striga* counts were less by over 90% in the intercropping systems, relative

to the sole maize crop without urea. In Siaya, reductions in *Striga* counts depended on the cutting regime, but not on the *Desmodium* species. *Striga* counts were lower when *Desmodium* was cut at 18 WAP (1.0 plants m⁻²) than when cut at 12 WAP (3.0 plants m⁻²) or 9 WAP (1.8 plants m⁻²).

3.4. Trade-offs between production objectives

Three objectives were considered in these production systems; namely, producing maize grain, producing *Desmodium* fodder, and reducing *Striga* to safeguard maize production. Indicators considered for each of these objectives were: cumulative maize grain yield over the 4-season period, cumulative *Desmodium* biomass yield at 4 WAP in SR2010 season (last simultaneous cutting in all treatments), and *Striga* counts in the last season (SR2010). In both sites, it was observed that *Desmodium* biomass can be produced with minimal effect on maize yield, since cumulative maize grain yields for a sole maize crop without urea are comparable or lower, relative to the intercropping systems (Fig. 6). Replacing *D. uncinatum* by *D. intortum* (and conducting the third cutting at 12 WAP in Siaya) increased *Desmodium* fodder production by 32–56%, but 6–9% of the maize grain production needed to be traded in. In Busia, all *Desmodium* intercropping systems effectively reduced *Striga* counts, while in Siaya, cumulative maize grain yields were correlated with the reduction in *Striga* counts, especially when intercropped with *D. uncinatum* ($R^2 = 0.64$, $P \leq 0.01$). *Striga* was most effectively controlled when *Desmodium* was cut at 18 WAP, which also tended to result in highest maize grain yields. Reduction in *Striga* counts was not related to *Desmodium* biomass production because *D. intortum*

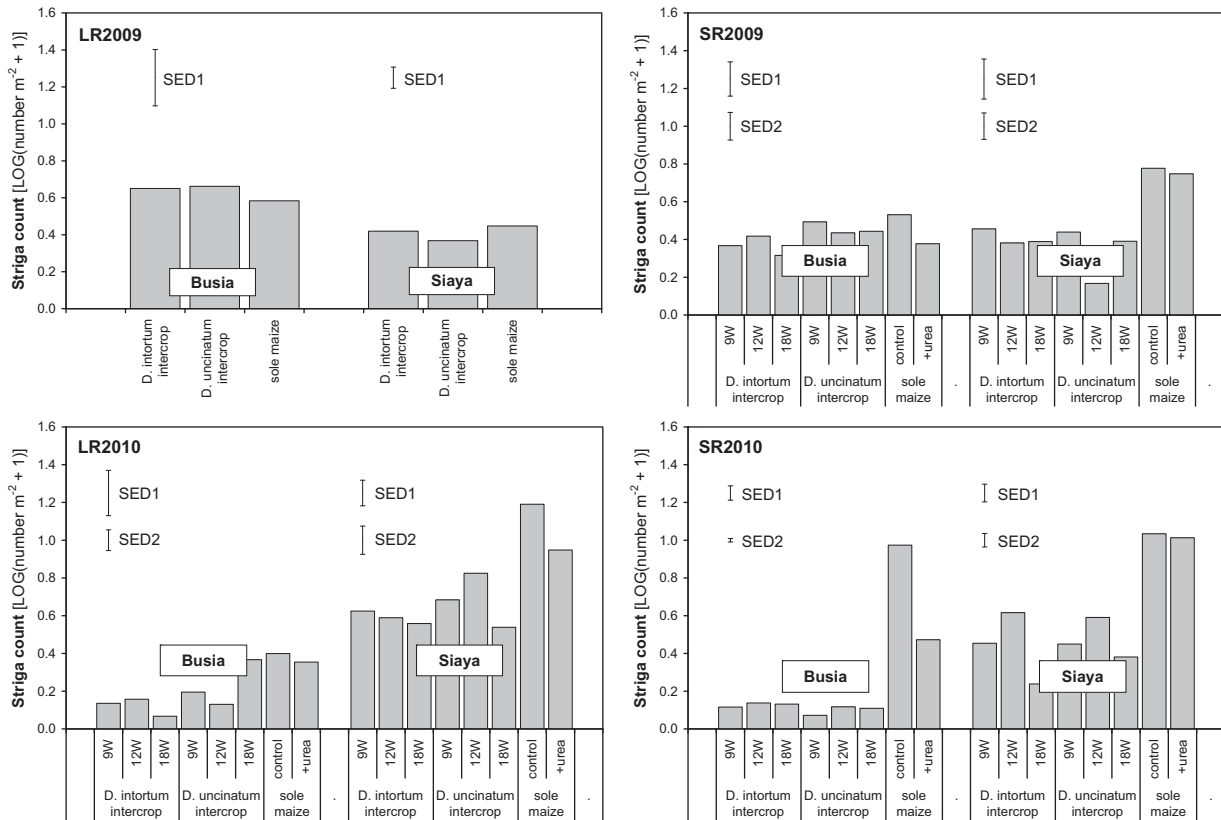


Fig. 5. *Striga* plant count from *Desmodium* intercropping systems with two *Desmodium* species and different cutting regimes. SED1, comparison of all treatments (one-way ANOVA) and SED2, interaction effect of *Desmodium* species and cutting regime (two-way ANOVA); W, weeks after planting maize; LR2009 and SR2009, long and short rains seasons of 2009, respectively, LR2010 and SR2010, long and short rains seasons of 2010, respectively.

gave higher biomass yields but was not more effective in controlling *Striga*.

3.5. Economic analysis

In the first season (LR2009), total crop production costs were higher in the *Desmodium* intercropping systems than in the sole maize system in all the sites. This was attributed to the cost incurred for purchasing *Desmodium* seeds and the extra labor required to plant and maintain the *Desmodium* (Fig. 7). Net benefits were significantly lower in the intercropping systems, and BCR values were less than one meaning that farmers incurred more costs compared to the benefits they obtained from a maize–*Desmodium* system during the first season (Table 2). After the second season, cumulated and discounted NBs were not affected by treatments in Busia or Siaya. In Siaya, the BCR was still significantly higher for the sole maize crop without urea application due to the lower cost. At the end of the third season, some BCRs were above 2, NBs were least for sole maize control in both sites and BCR ranged between 1.95 and 2.57 in Busia and between 3.24 and 3.80 in Siaya. Net benefits were not affected by *Desmodium* species or cutting regime. At the end of the fourth season (SR2010), cumulated NBs were twice as high in the *Desmodium* intercropping systems than for the sole maize crop without urea in Busia. By the fourth season, both the BCR and MRR in Busia were favorable and ranged between 1.76–2.36 and 2.47–3.67 USD USD⁻¹, respectively, irrespective of the treatments. In Siaya, average cumulated NBs were also lowest for the sole maize crop without urea at the end of the SR2010 season, and highest for the *Desmodium* intercropping systems, especially when the third cutting was done at 18 WAP (5680 USD ha⁻¹, BCR = 3.6 USD USD⁻¹) rather than at 12 or 9 WAP (5053 USD ha⁻¹, BCR = 3.3 USD USD⁻¹)

irrespective of *Desmodium* spp. The system with *D. uncinatum* cut at 18 WAP had highest net benefits, and the most favorable BCR and MRR, and was more profitable than the sole maize crop with urea application.

4. Discussion

Maize grain and stover yield from *Desmodium* intercropping was only higher by 26% compared to sole maize without urea (control) from third season in both sites (Figs. 2 and 3). This contradicted earlier results that reported higher increase in maize (>50% above control) in PPT (Khan et al., 2001, 2006, 2007a,b, 2008a,b), starting from the second season. The present results are attributed to a combination of factors. First, there was a slow establishment of *Desmodium* during the first season; an occurrence that has been reported in some studies (De Groote et al., 2010) and a good establishment was achieved during the second season (SR2009). Second, unlike the previous PPT studies that have used sole maize absolute control (no fertilizer), in this study all treatments including the sole maize control received basal P and in places like Siaya where P was more limiting than N, the N response was delayed in *Desmodium* intercropping. Third, even though frequent trimming of *Desmodium* was carried out, a reduction in maize production could result from the competition in the *Desmodium* intercropping, especially under periods of limiting moisture. Indeed farmers are advised to trim *Desmodium* twice (on the third [4 WAP] and fifth weeks following crop emergence) to eliminate any chances of *Desmodium* competing with maize. The treatments where trimming of *Desmodium* was delayed from the 4th to either the 9th, 12th or 18th week after maize planting, could have led to *Desmodium* competing with the young maize seedlings, resulting in a depressed maize grain

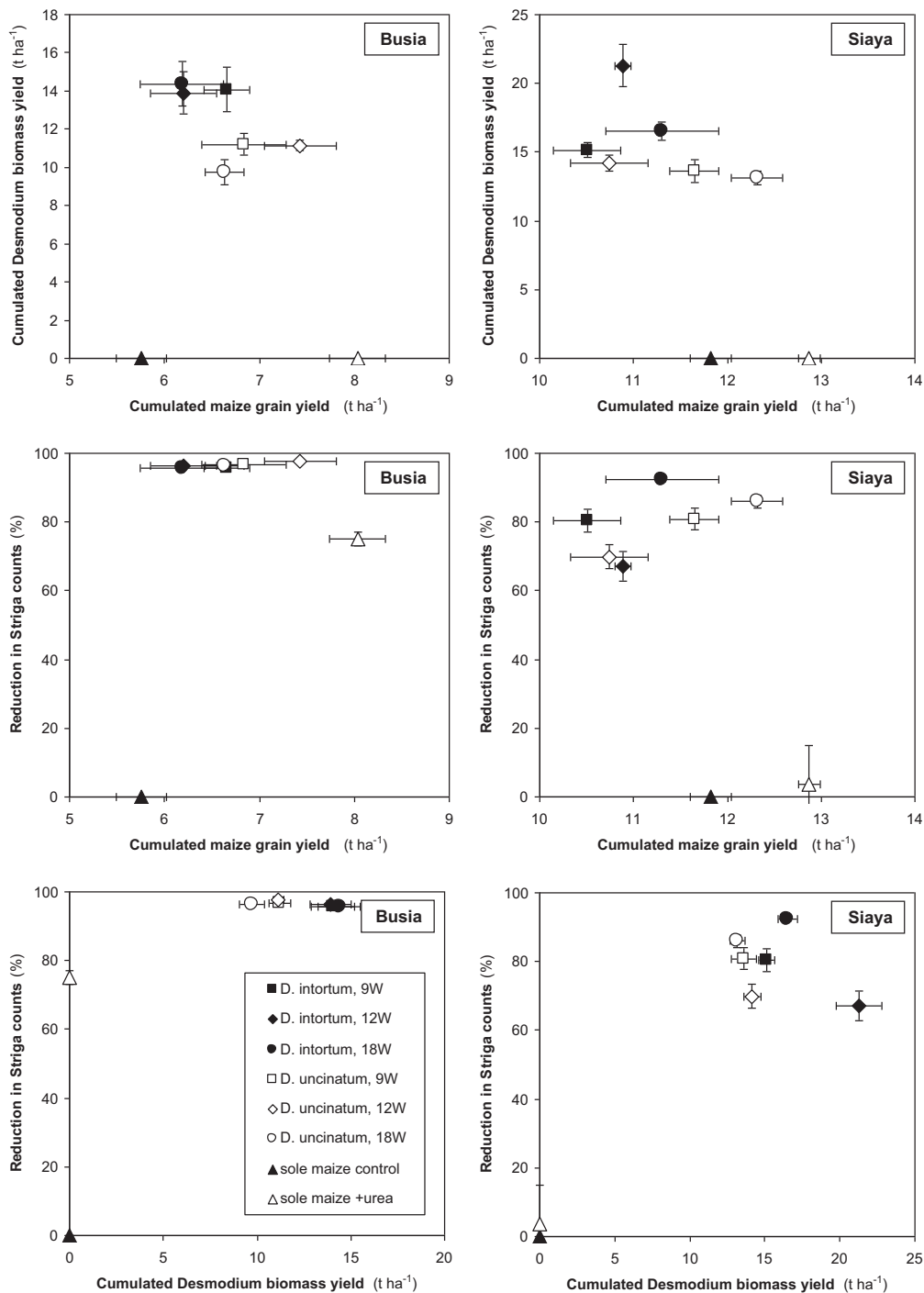


Fig. 6. Relationship between: (i) cumulative *Desmodium* biomass yield with cumulative maize grain yield and (ii) reduction in *Striga* count with cumulative maize grain and *Desmodium* biomass yields.

and stover yield. This notwithstanding, in sites where P is not limiting, inclusion of *Desmodium* spp. into maize cropping system can provide a substitute for inorganic N fertilizers to enhance crop growth and yield after *Desmodium* becomes well established. These results corroborate the findings of Vanlauwe et al. (2008) in western Kenya who recorded yield increases in PPT relative to a maize–bean intercrop after two seasons.

The *Desmodium* cutting regime had little impact on maize grain and stover yields in all the seasons though it had an impact on *Desmodium* fodder production in Siaya (Fig. 4). Maize may benefit equally from cut and uncut *Desmodium* due to a combination of

factors. Cutting *Desmodium* stimulates root turnover and N mineralization, which may supply N to the maize crop, and reduces root development, which may decrease above- and belowground competition with the maize crop (Pieter and Lehmann, 2000). In a system with uncut *Desmodium*, direct N transfer from *Desmodium* to the associated maize may enhance maize growth. Direct N transfer from *D. uncinatum* to *Paspalum commersonii* Lam. has been reported by Henzell (1962), but occurred only during the second year after establishment. It is, however, worthy to note that although this study did not assess the effect of varying *Desmodium* cutting regimes on forage quality, it is most likely that this may

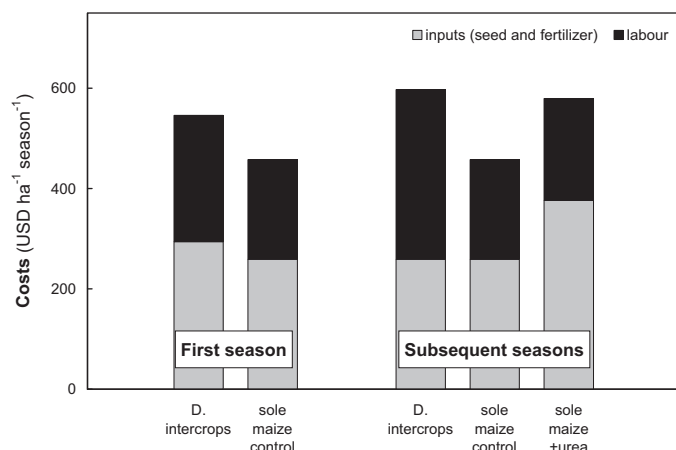


Fig. 7. Total costs across species, cutting regimes and seasons.

influence fodder quality and for crop–livestock farmers, quality would be important.

Although *D. intortum* consistently gave higher biomass than *D. uncinatum*, cumulative maize grain and stover yields in the *Desmodium* intercropping system were lower when intercropped with *D. intortum* than with *D. uncinatum*. This can be attributed to the morphological characteristics of the two species. *D. intortum* is a large trailing and scrambling plant with a deep tap root while *D. uncinatum* may grow several meters long by trailing over surrounding vegetation and has a large but shallow root system. It is therefore most likely that there was reduced competition for light and nutrients between maize and *D. uncinatum*, which resulted in enhanced maize growth. Visual observations of the two species' rooting systems showed that *D. intortum* had higher numbers of active nodules compared with *D. uncinatum*. Higher N fixation may

enable *D. intortum* to produce more biomass, and provide more N to the maize, which may partly compensate for the increased competition.

The economic benefit of *Desmodium* intercropping relative to sole maize systems was brought into perspective by computing NB, BCR and MRR. Production cost was higher in *Desmodium* intercropping compared to sole maize system during the first season (Fig. 7) due to additional cost of *Desmodium* seeds. However, production cost in the intercropping system reduced in the subsequent seasons but overall cost remained higher due to the additional labor requirement to maintain and cut *Desmodium*. This is contrary to earlier observations that reported reduced overall cost for PPT relative to sole maize with fertilizer (De Groote et al., 2010) and maize–bean intercrop (Khan et al., 2008a) in the later seasons, which possibly could be attributed to differences in labor costs in the two studies. In this study, it was observed that very careful weeding is required during the first season to allow *Desmodium* to establish while in the subsequent seasons, extra labor is required in *Desmodium* intercrop system for removal of weeds and cutting of *Desmodium*. However, there was a general reduced labor cost in land preparation and weeding under the *Desmodium* intercropping (Khan et al., 2008a). In the current study, net cumulative benefits in the *Desmodium* intercropping system were higher than in the sole maize control after 4 seasons irrespective of site, *Desmodium* species and cutting regime. The reported increase in net benefit not only originated from the increase in maize grain and stover yield, which occurred only after *Desmodium* was well established, but also from the value of the *Desmodium* fodder, which contributed 20–30% of the total profit. These results support the findings of De Groote et al. (2010) and Khan et al. (2008a) who reported higher initial establishment cost, but economic benefits after establishment of the *Desmodium*–maize intercropping system in western Kenya. The *Desmodium* cutting regime had little effect on the net benefits or costs, which is advantageous to farmers with crop–livestock

Table 2

Economic analysis of a *Desmodium* intercropping system with two *Desmodium* species and different cutting regimes, relative to a sole maize system with or without urea application over 4 subsequent seasons. Net benefits (NB) and benefit: cost ratios (BCR) are cumulative and discounted at 5% per season, and marginal rates of return (MRR) are calculated relative to the sole maize control.

	LR2009 ^b			SR2009			LR2010			SR2010		
	NB	BCR	MRR	NB	BCR	MRR	NB	BCR	MRR	NB	BCR	MRR
<i>Busia</i>												
<i>D. intortum</i> intercrop												
9W			–	1172	2.03	2.49	2503	2.48	3.32	2752	2.27	3.17
12W	124	1.23	–	820	1.71	0.98	2255	2.32	2.55	2438	2.10	2.24
18W			–	813	1.70	0.93	2279	2.34	2.66	2596	2.19	2.74
<i>D. uncinatum</i> intercrop												
9W			–	743	1.66	0.78	2160	2.30	2.62	2464	2.15	2.68
12W	78	1.15	–	970	1.86	1.74	2609	2.57	3.90	2927	2.36	3.67
18W			–	521	1.47	–	2114	2.28	2.56	2348	2.11	2.58
Sole maize control	264	1.58		563	1.63		1247	1.95		1298	1.76	
Sole maize + urea				720	1.71	1.30	1972	2.28	3.18	2123	2.04	2.47
SED1 ^a	120	0.24		249	0.25		394	0.27		448	0.22	
SED2 ^a				258	0.22		337	0.19		466	0.21	
<i>Siaya</i>												
<i>D. intortum</i> intercrop												
9W			–	1821	2.63	–	3744	3.24	0.23	4826	3.23	1.05
12W	385	1.71	–	2193	2.86	–	4230	3.41	1.27	5440	3.40	1.95
18W			–	2236	2.93	–	4074	3.38	1.02	5544	3.50	2.33
<i>D. uncinatum</i> intercrop												
9W			–	2204	2.96	–	4082	3.44	1.15	5283	3.45	2.07
12W	574	2.05	–	1932	2.69	–	3586	3.13	–	4664	3.13	0.66
18W			–	2445	3.15	0.37	4332	3.57	1.78	5816	3.67	3.10
Sole maize control	820	2.79		2355	3.64		3660	3.80		4344	3.55	
Sole maize + urea				2228	3.21	–	3706	3.41	0.20	4651	3.28	0.91
SED1 ^a	119	0.25		354	0.36		528	0.35		615	0.30	
SED2 ^a				183	0.15		260	0.14		335	0.15	

^a SED1 and SED2, respectively, indicate standard errors of differences for comparison of all treatments (one-way ANOVA) and for the interaction effect of *Desmodium* species and cutting regime in the intercropping systems alone (two-way ANOVA).

^b During LR2009, *Desmodium* cutting regimes were not yet imposed, and the values given are treatment averages.

farming systems as they can cut fodder according to their need throughout the season. After 3–4 seasons, the *Desmodium* intercropping system resulted in MRR values (>2.5) above the critical value of 1.18 (CIMMYT, 1988). The high MRR values (>1) is an indication that the technologies involving maize–*Desmodium* intercropping systems are likely to be adopted by farmers as every additional cost made relative to the sole maize crop is well compensated by an additional net benefit. The MRR was unaffected by *Desmodium* species or cutting regime in Busia, but highest with *D. uncinatum* cut at 18 WAP in Siaya. The reported profit should be taken with caution. For many farmers in the study area, *Desmodium* is not yet considered a valuable fodder because most animals still graze freely in open areas, and *Desmodium* is currently not widely grown. It is expected, nevertheless, that as the population increases, the demand and value of *Desmodium* fodder will rise, and net benefits will be higher than values reported here. In a scenario where *Desmodium* has no economic value, profitability would remain superior to a sole maize crop without urea due to the improvements in maize grain yield, which compensate for the additional labor cost. However, a sole maize crop with urea application would then be more profitable, as it is similar in total cost but results in higher grain yields than *Desmodium* intercropping.

Although weak correlations between *Desmodium* biomass with cumulative maize grain and *Striga* reduction were observed (Fig. 6), *Desmodium* intercropping system was highly effective in reducing *Striga* plant counts. Varying the time of cutting *Desmodium* did not affect *Striga* plant counts in Busia, while in Siaya, *Striga* emergence was lowest when the third *Desmodium* cutting was done at 18 WAP, irrespective of the *Desmodium* species. It was observed that from the second season, *D. intortum* and *D. uncinatum* equally reduced *Striga* counts in both sites. This agrees with findings by Khan et al. (2007b) that the two species may demonstrate comparable photochemical attributes, but this would need to be further investigated. The lower number of *Striga* plant counts in *Desmodium* intercropping system relative to sole maize system indicates a reduced potential for flowering and capsule production, and consequently a reduced capacity of increasing the seed bank in the soil (Massawe et al., 2004), which is crucial for *Striga* control in the long term. *Desmodium* spp. control *Striga* by a combination of shading, N addition and an allelopathic mechanism (Khan et al., 2002). The fewer *Striga* counts in sole maize with urea applied compared with control sole maize agree with findings in other studies that N addition in soils controls *Striga* (Khan et al., 2002; Showemimo et al., 2002).

The impact of soil fertility levels and climate on maize and *Desmodium* yields was clear in all seasons. Results showed that the effect of *Desmodium* intercropping and cutting regime on maize and *Desmodium* yields differed significantly between seasons and sites. Siaya consistently recorded higher maize and *Desmodium* yields. This was likely due to the better soil fertility as well as to the higher rainfall in Siaya than in Busia (Fig. 1). Response to urea application in the sole maize crop was significant starting from the second season in Busia, and from the third season in Siaya. The soil in Busia had a much lower N status than Siaya and continuous maize cropping without N inputs is thus expected to result in N deficiency more rapidly in the former site. Maize grain and stover yield in the *Desmodium* intercropping systems was only comparable to sole maize with urea from the third or fourth season. *Desmodium* yields were lower in Busia than in Siaya. It is likely that *Desmodium* was not able to fully express its potential in sandy, shallow and stony soils of Busia which had low organic matter content, but established well in the deep clayey soils of Siaya. Rainfall conditions may also interact with the performance of the system. It was observed that when moisture was not limiting, *Desmodium* regrew much faster after cutting, which affects N uptake from mineralized roots and the degree of competition with the maize crop. During the 4th

season (SR2010) in Busia, biomass yields were also drastically reduced due to the limiting moisture. It was, however, noted that *D. intortum* was able to withstand high temperatures with reduced wilting compared to *D. uncinatum*. The benefits of intercropping *Desmodium* with maize was, however, realized earlier in Busia than Siaya possibly because N was more limiting in Busia, an indication that *Desmodium* intercropping is likely to be more attractive to farmers in Busia than in Siaya in the long run. A further multi-local and multi-seasonal evaluation of the PPT would be required to investigate whether the system is also advantageous in terms of yield stability and sustainability.

5. Conclusion

The results showed clearly that when P is not limiting, inclusion of *Desmodium* spp. into maize cropping system might provide a substitute for inorganic N fertilizers to enhance crop growth and yield after *Desmodium* becomes well established. PPT studies have been recommended for resource poor farmers as a cheaper source of N and for the control of *Striga* on the basis of experiments that compared PPT with absolute controls (no fertilizer). The present study extends the recommendation of the PPT systems to farmers who apply phosphorus fertilizer as they can benefit from adopting PPT after *Desmodium* becomes established. Varying the time of cutting the *Desmodium* had little effect on maize yield, but affected *Desmodium* biomass production in one of the two trial sites. *D. intortum* consistently gave higher fodder yield compared to *D. uncinatum*, but resulted in somewhat lower maize grain yields. *Desmodium* intercropping was found to be a profitable enterprise for western Kenya in comparison with a sole maize system, but cumulated and discounted net benefits were only superior after 3–4 seasons; the system also requires a higher labor investment, both for establishment and for maintenance during subsequent seasons. Conducting the third *Desmodium* cutting at the end of the season (at 18 WAP) resulted in more effective *Striga* control in Siaya. With the dwindling farm sizes, incorporating *Desmodium* into maize–livestock cropping systems of western Kenya without compromising on maize yield and economic returns is likely to be attractive to the farming households in this part of Kenya.

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