Australian Journal of Crop Science AJCS
AJCS 6(8):1265-1274 (2012) ISSN:1835-2707

Effects of legume type, planting pattern and time of establishment on growth and yield of sweet sorghum-legume intercropping

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Abstract

Sweet sorghum is a popular grain crop grown in water stress prone areas in the world. Its sole stand leaves ample resources untapped. This study evaluated the feasibility of intercropping sweet sorghum using eight intercropping patterns composed of 2 x 2 x 2 factorial combinations of two legumes (viz. mung bean and soybean), two row patterns [viz. alternate single row (ASR) and double row (ADR)] and two seeding times (simultaneous and staggered seeding) with sole crops of sweet sorghum, mung bean and soybean in a randomized complete block design with three replicates during dry and wet seasons (2009-2010). Plant height, leaf area index (LAI) and grain yield between sole and intercropping were compared. The results showed that growth and grain yield of sweet sorghum were significantly ($p \leq 0.001$) reduced when intercropped with mung bean in both the seasons, except the yield with ASR pattern and staggered seeding in the dry season. However with soybean, sweet sorghum established in staggered seeding increased the grain yield in both ASR and ADR patterns in the dry season (5.5 t ha^{-1}), and at par in the wet season compared to its sole crop (5.4 t ha^{-1}). All intercropping patterns had land equivalent ratio (LER) above unity. Overall outputs of carbohydrate, protein, fat, and total digestible energy during the dry season were increased by 0.4, 0.4, and 0.3 t, and 22 MJ ha^{-1}, respectively, and during the wet season by 0.1, 0.4 and 0.2 t and 14 MJ ha^{-1}, respectively, in sweet sorghum-soybean intercropping compared to sole cropped sweet sorghum.

Keywords: Intercropping, sweet sorghum, legume, row pattern, time of seeding, grain yield, food value, energy output.
Abbreviations: ASR- Alternate single row; ADR- Alternate double row; BNF- Biological nitrogen fixation; ETo- Reference evapotranspiration; LAI- Leaf area index; LER- Land equivalent ratio.

Introduction

Sweet sorghum is grown for multiple purposes worldwide, such as, a source of food, feed, fiber, and fuel from its biomass, and seed (Dajue, 1995). It has a good potential to tolerate adverse environmental conditions, such as drought (Woods, 2000) and temperature fluctuations (Sree et al. 1999). It's rapid growth and high biomass production helps overcome unfavorable environmental conditions (Reddy and Sanjana, 2003), and the short maturity period favors successful cultivation of the crop on marginal soils (Griffee, 2000; Nahar 2011) with low soil moisture in temperate, tropical and sub-tropical climates (Dajue, 1995). To make the best use of available resources like land, light and nutrition, sweet sorghum acreage could be increased by adopting intercropping, a type of multiple cropping in which two or more crops are grown simultaneously or staggered on the same land (Ranamukhaarachchi, 1985; Mpairwe et al., 2002; Azraf et al., 2006; and Catherine et al., 2007). A few researchers reported that interspecific competition in intercropping can affect growth, development and yield of each component crop due to differences in species and microclimate, and mutual shading (Rana et al., 2001; Rashid and Hamayatullah, 2003). This unfavorable and unfair acquisition of resources resulting from inter-specific competition is needed to be alleviated through agronomic management approaches, such as changing the intercrop and altering the planting pattern and/or time of seeding. Grain and forage sorghum types are widely grown in intercropping with legumes for increasing crop yields per unit area of land over sole stands. But, little information is known about the influence of legumes on the performance of sweet sorghum in intercropping in terms of growth and yield and land productivity. On the other hand, wide differences in the phenological development and growth rate and patterns of sweet sorghum and legumes may demand various adjustments in agronomic practices, such as changing planting pattern and seeding time, to develop a compatible and productive intercropping pattern. The overall productivity of sweet sorghum and legume would depend on the compatibility of the component crops in terms of sharing resources and resource-use efficiencies with integrated temporal effects by modifying and sequential setting up of agronomic practices. However, the literature available on these aspects on sweet sorghum-legume is scanty. Therefore, this study investigated the effects of selected legumes, planting pattern and time of seeding on growth and grain yield, and food values of sweet sorghum-legume intercropping systems.

Results

Growth performance in sole and intercropping

Plant height: The height of sweet sorghum was compared between seasons, and found to be significantly greater ($p \leq 0.001$) in the dry season (2.0 m) than in the wet season (1.6 m) (Table 1). Sole cropped sweet sorghum had a plant height of 2.3 m in the dry season and 1.9 m in the wet season, and were greater than intercropping stand with mung bean ($p \leq$

0.001), but not with soybean ($p > 0.05$) (Supplementary Table 1). In intercropping, the height of sweet sorghum was significantly reduced ($p \leq 0.05$) by alternate single row pattern (ASR; 2.1 m) compared to alternate double row pattern (ADR; 2.0 m) in the dry season, and also significantly ($p \leq 0.05$) reduced by mung bean (1.5 m) compared to soybean (1.8 m) and by simultaneous seeding (1.5 m) compared to staggered seeding (1.7 m) in the wet season (Table 2). Within intercropping, plant height was also influenced by the interaction between the legume type and time of seeding in the dry season (Fig 1a): the height was significantly decreased from 2.0 to 1.5 m in simultaneous seeding compared to staggered seeding when sweet sorghum was associated with mung bean, but the decrease was not significant with soybean regardless of time of seeding. The overall effects on plant height was such that the ASR pattern showed a greater plant height (1.7-1.8 m) than the ADR pattern (1.6-1.7 m) in the dry season, but not in the wet season, and mung bean led to a reduction in plant height of sweet sorghum compared to its sole cropping in both the seasons. Plant height of intercropped mung bean significantly varied ($p \leq 0.001$) due to season: dry season crop had greater height (0.44 m) than wet season crop (0.37 m), but within each season, there was an insignificant difference ($p > 0.05$) between sole and intercropping stands (Supplementary Table 2). Among the main factors, simultaneous seeding caused a greater reduction in mung bean height (0.2-0.5 m) than staggered seeding (0.5-0.8 m) in both the seasons (Table 3). Plant height of soybean did not vary significantly ($p > 0.05$) between the dry and wet seasons and between sole and intercropping stands (Supplementary Table 2). In intercropping, greater plant height was observed in the ADR pattern (1.0 m) compared to the ASR pattern (0.9 m) during the wet season only and in staggered seeding (1.0 m) compared to simultaneous seeding, 0.6 m in the dry season and 0.8 m in the wet season (Table 4). This showed that intercrop competition resulted in a reduction of plant height of both sweet sorghum and legumes, but the ASR pattern for sweet sorghum, ADR pattern for legumes and staggered seeding for both components provided spatial and temporal advantages by reducing competitive effects.

Leaf area index (LAI): Seasonal effect on LAI of sweet sorghum was highly significant ($p \leq 0.001$): dry season had greater LAI (5.7) than wet season had (Table 1; 5.1). Within each season, sole cropped sweet sorghum had the highest LAI: 6.2 in the dry season and 5.6 in the wet season, and corresponding values in intercropping were lower compared to sole cropping (Supplementary Table 1). Soybean did not significantly reduce ($p > 0.05$) the LAI of sweet sorghum, but mung bean caused a significant reduction ($p \leq 0.001$) in the LAI: 4.9 during wet season and 5.4 during dry season compared to sole cropping. Within intercropping during dry season, there was a significant reduction ($p = 0.05$) in LAI with ADR pattern (5.6) compared to ASR pattern (Table 2; 5.8). Furthermore, there were significant interactions between legume type and time of seeding ($p \leq 0.05$) in the dry (Fig 1b) and wet (Fig 1c) seasons, and between planting pattern and the time of seeding in the wet season ($p \leq 0.05$; Fig 1d). The former interaction shows that sweet sorghum intercropped with soybean and established in staggered seeding had the highest LAI, and was significantly greater than the rest of the combinations in the dry season. Mung bean reduced the LAI of sweet sorghum significantly at both seeding times, and the reduction was highest with simultaneous seeding. The LAI during wet season also followed the same trend as in the dry season. According to the latter interaction, staggered seeding had the highest LAI when combined with ASR pattern, while ADR combined with simultaneous seeding had the lowest LAI (Fig 1d). The overall results indicated that intercropping led to the reduction in LAI of sweet sorghum compared to sole cropping, but staggered seeding and the ASR pattern reduced the reduction in LAI compared to sole crop. Leaf area index of mung bean was significantly reduced ($p \leq 0.001$) in the wet season (2.2) compared to the dry season (2.6) and was significantly greater ($p \leq 0.05$) in sole cropping (2.9-4.1) than in intercropping (1.9-2.8) in both the seasons (Supplementary Table 2). In intercropping, LAI of mung bean was significantly increased in ADR pattern (3.4) compared to ASR pattern (2.2) during dry season and in staggered seeding (2.7-3.4) compared to simultaneous seeding (1.7-2.2) during both the seasons. The response of LAI of soybean was also similar to mung bean (Supplementary Table 2; Table 4).

Yield performance in sole and intercropping

Grain yield of sweet sorghum was significantly ($p \leq 0.001$) decreased during the wet season (4.5 t ha^{-1}) compared to the dry season (Table 1; 5.3 t ha^{-1}) and was highest in sole stand (5.4 t ha^{-1}) than in intercropping stands (Supplementary Table 1). However, a significant difference ($p \leq 0.001$) in the yield was observed only between sole cropping and in intercropping with mung bean (4.1-5.1 t ha^{-1}). There were significant effects ($p \leq 0.05$) of legume type, planting pattern and time of seeding on grain yield of intercropped sweet sorghum during the wet season: grain yield was decreased with mung bean (4.1 t ha^{-1}), ADR pattern (4.4 t ha^{-1}) and simultaneous seeding (4.3 t ha^{-1}) compared to soybean (5.0 t ha^{-1}), ASR pattern (4.7 t ha^{-1}) and staggered seeding (4.7 t ha^{-1}), respectively (Table 2). In the dry season, there was a three-way interaction for grain yield (Fig 2): sweet sorghum intercropped with mung bean and also with soybean in staggered seeding with ASR pattern as well as with soybean in staggered seeding with ADR pattern gave the same grain yield (5.5 t ha^{-1}), which was significantly greater than both sole crop and rest of the combinations. On the other hand, mung bean in simultaneous seeding drastically reduced the grain yield of sweet sorghum at both planting patterns. Seed yield of both mung bean and soybean was greater in sole crops than respective intercropping stands in both the seasons (Supplementary Table 2). The competition free environment of both mung bean and soybean led to full yield of both crops in sole stand, whereas in intercropping competition from sweet sorghum caused the reduction in the seed yield of both legumes (Tables 3 and 4).

Land Equivalent Ratio (LER)

Land equivalent ratio (LER) is defined as the land area required as sole crops to obtain the same yield from intercropping under the same management levels (Willey, 1979). An LER of 1.0 shows that intercropping produces the same yields as of sole cropping, and above 1.0 giving greater yields than sole crops. The LER declined in the dry season (1.6) compared to the wet season (1.9) (Table 1). Furthermore, intercropping sweet sorghum with mung bean and soybean gave greater LERs than 1.0 indicating yield advantages over sole cropping (Table 5). Within intercropping patterns in the dry season, LER values were significantly ($p \leq 0.001$) greater in sweet sorghum-soybean patterns (1.7) than in sweet sorghum-mung bean patterns (1.5), in ADR pattern (1.8) than in ASR pattern (1.5), and in staggered seeding (1.9) than in simultaneous seeding (1.4). In

Table 1. Seasonal analysis of growth and yield parameters of intercropped sweet sorghum and nutritive values of sweet sorghum-legume intercropping during dry and wet seasons 2009-2010.

Parameter	MS for season	Dry season	Wet season	MS for error	CV, %
Intercropped sweet sorghum					
Plant height	1.814***[1/]	2.02 ± 0.07	1.63 ± 0.14	0.098	6.15
LAI	4.514***	5.72 ± 0.38	5.11 ± 0.31	0.007	5.33
Grain yield	6.520***	5.25 ± 0.39	4.51 ± 0.56	0.059	5.41
LER	0.623*	1.63 ± 0.35	1.86 ± 0.34	0.129	20.60
Sweet sorghum + legume Intercropping					
Carbohydrate	2.350***	4.19 ± 0.32	3.75 ± 0.45	0.026	4.31
Protein	0.047**	0.88 ± 0.10	0.82 ± 0.10	0.001	5.03
Fat	0.013***	0.29 ± 0.04	0.26 ± 0.03	0.001	9.12
Energy	1137.243***	95.92 ± 7.69	86.18 ± 10.40	13.30	4.23

1/ ** and ***- indicate the significance of the comparison between sole and intercropping at p=0.01 and 0.001, respectively.

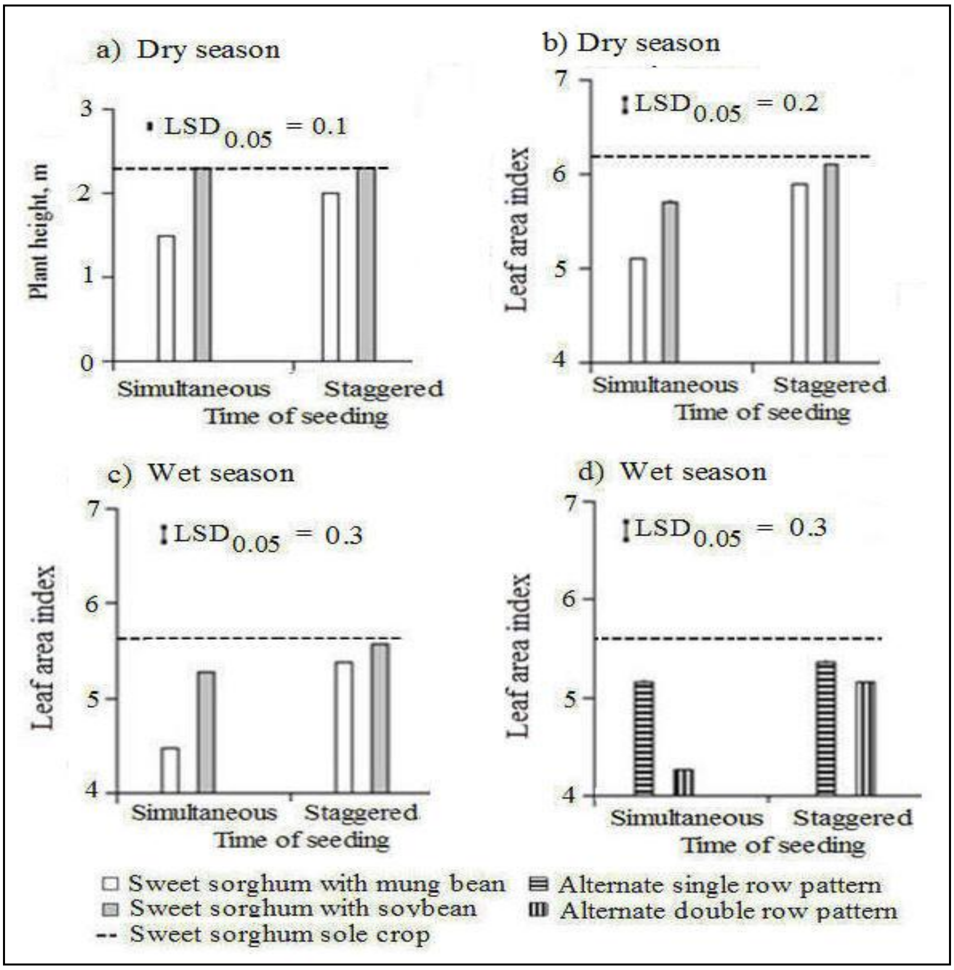

Fig 1. Effects of two-way interactions between legume type and time of seeding for plant height during dry season (a), and for LAI in both dry (b) and wet (c) seasons, and between planting pattern and time of seeding for LAI of sweet sorghum in wet season (d)

the wet season, there was an interaction ($p \leq 0.001$) between legume type and time of seeding for LER (Fig 3). According to this interaction, the highest LER was in soybean and simultaneous seeding combination (2.2), whereas the lowest was in mung bean and simultaneous seeding combination (1.45).

Nutritional status of cropping systems

Intercropping had greater total output for carbohydrate, protein, fat and digestible energy compared to sole cropped sweet sorghum in both the seasons (Supplementary Table 3). In the dry season, these values were slightly higher compared to wet season (Table 1). Soybean increased the nutritional value of all the components in intercropping compared to mung bean. There were significant effects of legume type, planting pattern and time of seeding in the wet season and of planting pattern and time of seeding in the dry season on the output of carbohydrate. All the main factors had significant influence in the dry season and of legume type and time of seeding in the wet season on protein and energy outputs (Table 6): sweet sorghum-soybean intercropping compared to sweet sorghum-mung bean intercropping and staggered seeding compared to simultaneous seeding produced significantly higher ($p < 0.05$) outputs of carbohydrate, protein and energy; protein was higher in the ADR pattern compared to the ASR pattern, and the opposite was true for the output of energy; output of carbohydrate was higher in the ADR pattern compared to the ASR pattern in the dry season and vice versa in the wet season (Table 6).

Table 2. The effects of legume type, planting pattern and time of seeding on plant height, LAI and grain yield of sweet sorghum in intercropping during dry and wet seasons 2009-2010.

Treatment	Dry season		Wet season	
	Plant height, m	LAI	Plant height, m	LAI
Sole crop[1/]	2.3 ± 0.1	6.2 ± 0.4	1.9 ± 0.2	5.6 ± 0.4
Intercropping				
Type of intercrop				
Mung bean	1.9 ± 0.1	5.4 ± 0.3	1.5 ± 0.2	4.9 ± 0.3
Soybean	2.2 ± 0.1	6.0 ± 0.4	1.8 ± 0.1	5.3 ± 0.3
LSD (0.05)	0.1	0.2	0.1	0.3
Planting pattern[2/]				
ASR	2.1 ± 0.1	5.8 ± 0.5	1.7 ± 0.2	5.3 ± 0.4
ADR	2.0 ± 0.1	5.6 ± 0.3	1.6 ± 0.2	4.9 ± 0.3
LSD (p=0.05)	0.1	0.2	ns[3/]	0.3
Time of seeding				
Simultaneous	1.8 ± 0.1	5.5 ± 0.4	1.5 ± 0.1	4.8 ± 0.4
Staggered	2.3 ± 0.1	5.9 ± 0.4	1.7 ± 0.2	5.4 ± 0.3
LSD (p=0.05)	0.1	0.2	0.1	0.3
CV, %	2.4	3.5	6.2	5.3

1/ Sole crop performance of each parameter is shown for comparison purpose; 2/ ASR – Alternate single rows; ADR – Alternate double rows; 3/ ns – Not significant at p=0.05.

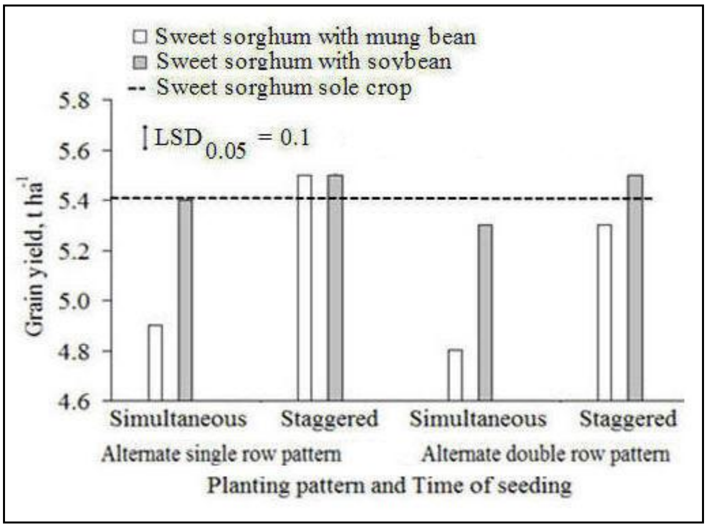

Fig 2. Effects of three-way interaction among legume, planting pattern and time of seeding for grain yield of sweet sorghum during dry season.

For the output of fat, there were significant two-way interactions: between legume type and time of seeding in both dry (Fig 4a) and wet (Fig 4b) seasons, and between the legume type and the planting pattern in the wet season only (Fig 4c). The former interaction showed that sweet sorghum-soybean intercrop gave the highest output of fat in staggered seeding, which was significantly greater than in all other combinations, as well as sole cropped sweet sorghum. Sweet sorghum-soybean intercropping in simultaneous seeding also gave greater output of fat than sole cropped sweet sorghum in both the seasons. The latter interaction also indicated a similar performance of soybean compared to mung bean, and the ADR pattern compared to the ASR pattern; and output of fat was higher in the case of former legume and pattern.

Discussion

Growth and yield parameters of intercropped sweet sorghum were comparatively lower in wet season compared to dry season: this was attributed to its sensitivity to high water table resulted from frequent and intense rainfall (Promkhambut et al., 2010) and reduced light intensity affecting photosynthesis and hence assimilate availability in the wet season (Singh et al., 1974). Growth and yield of sweet sorghum including plant height, LAI, and grain were lower in intercropping compared to its sole cropping. The reduction in growth and yield of sweet sorghum was significantly greater when intercropped with mung bean than with soybean, but the difference was insignificant in the latter. This would be due to the competition between sweet sorghum and companion legume for resources. However, soybean did not exert a greater pressure on associated sweet sorghum compared to mung bean, and thus having insignificant reduction in the above parameters. Varying abilities among crops to acquire growth resources from different environments have been reported (Juli and Mike, 2001). Due to such abilities and under varying environmental conditions, low competitiveness and improved performance of soybean compared to mung bean could have minimized

Table 3. The effect of planting pattern and time of seeding on plant height and LAI of mung bean in intercropping during dry and wet seasons 2009-2010.

Treatment	Dry season		Wet season	
	Plant height, m	LAI	Plant height, m	LAI
Sole crop[1/]	0.9 ± 0.4	4.1 ± 1.4	0.6 ± 0.1	2.9 ± 0.2
Intercropping				
Planting pattern[2/]				
ASR	0.6 ± 0.2	2.2 ± 1.1	0.3 ± 0.1	2.0 ± 0.3
ADR	0.6 ± 0.4	3.4 ± 1.3	0.4 ± 0.1	2.4 ± 0.2
LSD (p=0.05)	ns[3/]	0.3	ns	ns
Time of seeding				
Simultaneous	0.5 ± 0.3	2.2 ± 1.1	0.2 ± 0.1	1.7 ± 0.3
Staggered	0.8 ± 0.3	3.4 ± 1.3	0.5 ± 0.1	2.7 ± 0.3
LSD (p=0.05)	0.3	0.3	0.1	0.4
CV, %	35.4	28.1	18.6	13.4

1/ Sole crop performance of each parameter in mung bean; 2/ ASR – Alternate single rows; ADR – Alternate double rows; 3/ ns – Not significant at p=0.05.

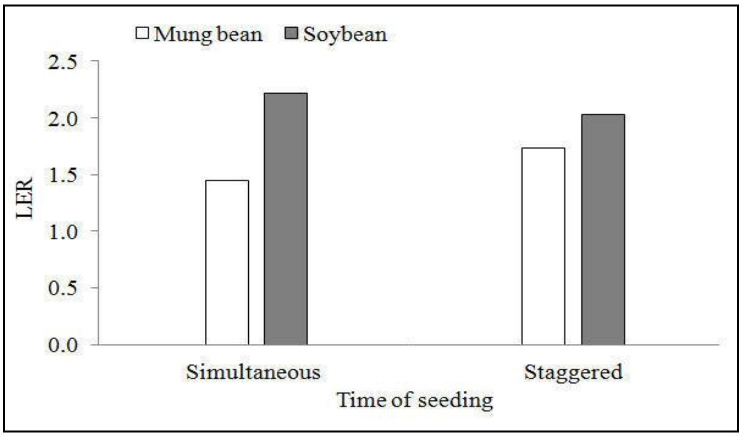

Fig 3. Effects of two-way interaction between legume type and time of seeding for LER during wet season

the adverse competition on sweet sorghum, thus promoting the overall outcome. These results are in congruity with the observations of Dhope et al. (1992), who reported a reduction of growth and yield of sorghum due to mung bean in intercropping. There was a decrease in the growth and yield of sweet sorghum in the ADR pattern compared to ASR pattern. In the ADR pattern, inter-row spacing between sweet sorghum and associated legume was much reduced compared to ASR pattern, thus increased the proximity of the component crops. This proximity would have promoted inter-specific competition between sweet sorghum and legume established in ADR pattern for available moisture and nutrients in the soil profile (Nelson and Weaver, 1980), mutual shading (Jasi et al., 2003), and early senescence of sweet sorghum leaves under competitive situation (Guo et al., 2004; Tollenaar and Daynard, 1978). Furthermore, greater penetration of solar radiation in ADR pattern due to wider inter-row spacing (60 cm rows) provided appropriate environment for legume to grow and compete with sweet sorghum when compared to ASR pattern with narrower (45 cm) inter-row spacing. Growth and yield of intercropped sweet sorghum almost sustained in the ASR pattern due to similar microclimate compared to its sole cropping, but concomitant reduction in radiation penetration by sweet sorghum deprived the legume to continue with normal growth. This in turn reduced the competitive ability of legume on sweet sorghum and reducing growth and yield. These results are in agreement with the findings of Thippeswamy and Alagundagi (2001) who observed significant differences of growth and yield of component crops due to changing planting pattern in intercropping. In this study, reduction in grain yield of sweet sorghum was observed in the combination of ADR pattern and simultaneous seeding compared to ASR pattern and staggered seeding as a result of interaction. This reduction may be attributed to intra- and inter-specific competitions because of decreased spatial separation within sweet sorghum rows (30 cm) and between sweet sorghum and legume rows (20 cm) in the ADR pattern compared with the ASR pattern in which sweet sorghum rows were separated by 45 cm and sweet sorghum and legume rows were separated by 22.5 cm. Intimacy of rows triggers below and above ground interactions for the same resource pool and aeration (Mutungamiri et al., 2001). Therefore, the intra-specific proximity of sweet sorghum rows in the ADR pattern increased mutual shading in sweet sorghum. On the other hand, it improved light availability to companion legume growing at the ground level, enhancing the growth of legume in the ADR pattern than in the ASR pattern. Staggered seeding had temporal separation of growth periods of component crops. This reduced the inter-specific competition for light and other resources compared to simultaneous seeding: in the latter, companion legume could not provide N fixed by biological nitrogen fixation (BNF) for sweet sorghum growing along with it and hence leading to inter-specific competition. Resultantly, the combination of the ASR pattern and staggered seeding favored the growth and yield of intercropped sweet sorghum compared to the combination of the ADR pattern and simultaneous seeding. The positive influence of the interaction between ADR pattern and staggered seeding increased the grain yield of intercropped sweet sorghum compared to sole stand. Overall,

Table 4. The effect of planting pattern and time of seeding on plant height and LAI of soybean in intercropping during dry and wet seasons 2009-2010.

Treatment	Dry season		Wet season	
	Plant height, m	LAI	Plant height, m	LAI
Sole crop[1/]	1.1±0.4	3.8±1.5	1.1±0.1	2.7±0.95
Intercropping				
Planting pattern[2/]				
ASR	0.8±0.6	2.0±1.4	0.9±0.1	1.4±0.75
ADR	0.8±0.4	3.0±1.4	1.0±0.1	2.1±0.75
LSD (p=0.05)	ns[3/]	0.8	0.1	ns
Time of seeding				
Simultaneous	0.6±0.5	2.0±1.4	0.8±0.1	1.1±0.7
Staggered	1.0±0.5	3.0±1.4	1.0±0.1	2.4±0.9
LSD (p=0.05)	0.4	0.8	0.1	1.1
CV, %	34.4	21.9	5.4	43.5

1/ Sole crop performance of each parameter in soybean is shown for comparison purpose; 2/ ASR – Alternate single rows; ADR – Alternate double rows; 3/ ns – Not significant at p=0.05;

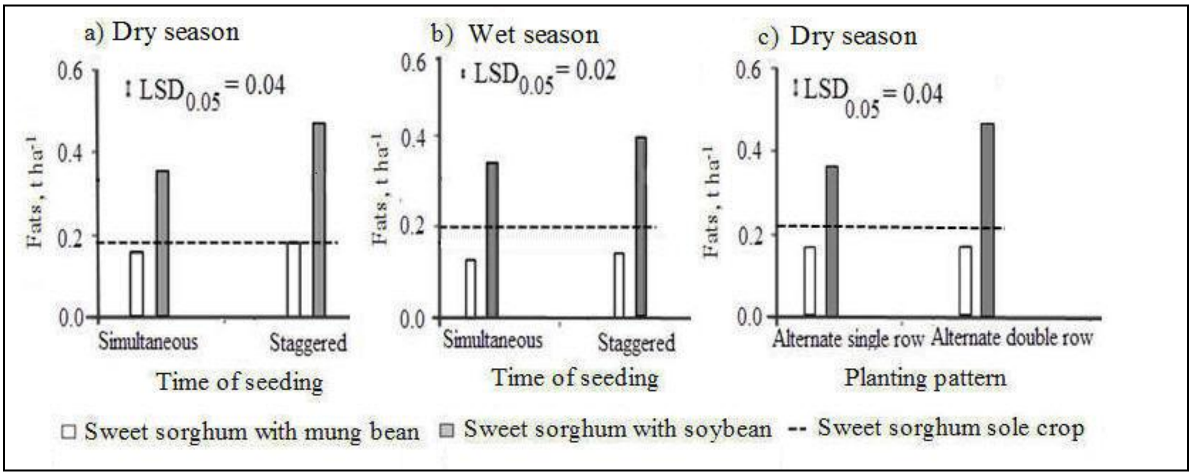

Fig 4. Effects of two-way interactions between type of legume and time of seeding during dry (a) and wet (b) seasons, and between planting pattern and time of seeding during dry season (c) for the total output of fat in intercropping.

grain yield of sweet sorghum intercropped with soybean in ADR pattern and staggered seeding was increased compared to sole cropping. These increases could have been attributed to the conducive environment provided by intercropped legume, planting pattern and time of seeding (Sharma et al., 2000; Thippeswamy and Alagundagi, 2001, Nnko (1982) and availability of adequate nutrients, especially N, in staggered seeding (Issahaku, 2010; Cochran and Schlentner, 1995).The purpose of growing legumes with sweet sorghum was to gain yields in addition to sweet sorghum, and also to utilize idling resources by legumes as early as possible before sweet sorghum commences its high demanding period for such resources. Addition of yield by intercropped legume to the overall production would give yield advantages (Willey, 1979). Growth and yield of mung bean and soybean were higher in the ADR pattern than in the ASR pattern. The contributory factor is the greater availability and better distribution of solar radiation in the former compared to latter. Similar yield responses in intercropped mung bean and soybean in ASR and ADR patterns were also reported by Baker (1975). On the other hand, staggered seeding had higher growth and yield than simultaneous seeding in the current study, and the contributory factor is the temporal separation of vegetative growth period of sweet sorghum and legume by staggering the seeding of sweet sorghum by one month later than legume. Simultaneous seeding caused overlapping of vegetative period of component crops and hence, causing early intercrop competition leading to reduction of growth and yield. The competition for solar radiation and soil nutrition, dominance effect due to plant height and shading and allelopathic effects of sweet sorghum appeared to have been greater in simultaneous seeding than staggered seeding and hence contributing to reduction of seed yield of legumes (Nnko, 1982; Moosavi et al., 2011). The land equivalent ratio (LER) was 14 % higher in sweet sorghum-soybean intercropping compared to sweet sorghum-mung bean intercropping in the dry season. Among the treatment effects within dry season, sweet sorghum-soybean intercropping had 23 % higher LER in the ADR pattern than the ASR pattern, and 34 % higher in staggered seeding than simultaneous seeding. Higher yields and LER values in sweet sorghum-soybean pattern with simultaneous seeding are in agreement with the observations of Sharma et al. (2000), Thippeswamy and Alagundagi (2001), and Nnko (1982). As per interaction during wet season, LER of 2.2 in soybean and simultaneous seeding combination and of 2.0 in soybean and staggered seeding combination were a result of increased grain yields of sweet sorghum above its sole crop and soybean giving its yield almost close to its sole crop. The enhancement of the yield of sweet sorghum and nearly unaffected yields of soybean could be due to several reasons: 1) the former was a result of reduced competition between sweet sorghum and soybean due to relatively lower plant population of the latter compared to mung bean; 2) in the latter, soybean variety being an indeterminate type, the shading by sorghum may have been recovered by the formation of new leaves (Shibles et al., 1987); and, 3) soybean is a better N fixer compared to mung bean (Tien et al., 2002). These characteristics may have given better advantage in the sweet sorghum and soybean combination than in the sweet sorghum and mung bean combination.

Materials and methods

Experimental site and climatic conditions

The study was carried out in dry and wet seasons 2009-2010 at the Agricultural Systems and Engineering Research Farm, Asian Institute of Technology (AIT), Thailand (13° 44' N, 100° 30' E). The soil type was Ongkarak clay (very fine texture, mixed acid, isohyper, sulfic tropaquepts) (Cheyglinted, 2000). Accumulated solar radiation (global) and average air temperature were higher during the dry season (791.13 KW m^{-2}, 29.37 ^{o}C, respectively) than during the wet season (720.73 KW m^{-2}, 28.73 ^{o}C, respectively), whereas, the total rainfall was greater in the wet period (1054.10 mm) than in the dry period (87.64 mm).

Treatments and experimental layout

Eight sweet sorghum intercropping treatments composed of 2 x 2 x 2 factorial combination of two legumes (viz. soybean or mung bean), two planting patterns [viz. alternate single rows (ASR) and alternate double rows (ADR)], two seeding times (viz. simultaneous and staggered), and three sole crops [viz. sweet sorghum, mung bean and soybean] were tested in a randomized complete block design (RCBD) with three replicates. The planting pattern of ASR comprised of single rows of sweet sorghum seeded at 45 cm spacing and single rows of legume seeded in the middle of two sorghum rows. In the ADR pattern, sorghum was established as paired rows at 30 cm within a pair and 60 cm between two pairs, and two rows of mung bean or soybean established in between paired rows of sweet sorghum. Paired rows of legumes were spaced at 20 cm from adjacent sweet sorghum rows. Within row spacing for sweet sorghum was 15 cm while, 10 and 20 cm provided for mung bean and soybean, respectively. In simultaneous seeding, both sweet sorghum and legume were established at the same time, whereas, sweet sorghum was seeded one month after seeding the legume in staggered seeding. The same plant densities used for sole crops were maintained in intercropping for sweet sorghum (148,148 plants ha^{-1}), mung bean (222,222 plants ha^{-1}) and soybean (111,111 plants ha^{-1}) due to slow initial growth habit of sweet sorghum. Each row of legume had the same number of seedlings, as in its sole crop. Accordingly, mung bean and soybean in both sole- and intercropping had 10 and 5 plants m^{-2}, respectively. Plot size was 3.6 m × 6.0 m. Plots within each replicate were separated by one meter wide area and blocks by two meter area.

Experimental management

Land was prepared using a disc harrow and a rotary tiller, and leveled with a plank. Plots were prepared as raised beds. Recommended varieties of sweet sorghum (KKU-40), mung bean (Chinat-72 – determinate type) and soybean (Nakhorn Swan-1 – indeterminate type) in Thailand were used (DOA, 2012). In the dry season experiment, all legumes and sweet sorghum were seeded on 1st December 2009 for simultaneous seeding. For staggered seeding, sweet sorghum was seeded one month after seeding the legume. In the wet season experiment, seeding was done on July 10, 2010 for simultaneous seeding, and on August 10, 2010 for staggered seeding. Plots were maintained at non-water stressed conditions by applying water daily using sprinkler irrigation system until seedling emergence. After seedling emergence, irrigation was provided by calculating the water requirement taking into consideration the reference evapotranspiration (ETo) and crop growth stage specific crop coefficient (Kc) and soil infiltration rates. As fertilizers, 80, 30 and 30 kg ha^{-1} of N, P and K, respectively, were applied to both sole and intercrops. Total amount of P and K was applied to all plots as basal dressing. However, the dose of N was divided into two splits and applied 50 % at seeding and the remainder at 50 % booting for simultaneous seeding. For staggered seeding, N was applied in three splits, i.e. 25 % at legume seeding, 25 % at sweet sorghum seeding, and the remainder at booting of sweet sorghum. For sole crops of mung bean and soybean, N, P and K were applied at the rate of 30 kg ha^{-1} each at the time of seeding. Weeds were manually removed from all the plots. Carbofuran granules (2 %) (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate), carbaryl (1-Naphthyl N-methylcarbamate) and Melathion [[(Dimethoxyphosphinothioyl) thio]butanedioic acid diethyl ester] at the rate of 50 kg ha^{-1}, 0.28 kg ha^{-1} and 0.5 L ha^{-1} respectively, were applied to all plots in order to control shoot fly and aphids.

Plant sampling and measurements

Plants were sampled for growth and yield related observations. For leaf area estimation, one meter row section in sweet sorghum plots was randomly selected and harvested at panicle emergence. Length and width of each leaf were measured and leaf area was calculated by multiplying length and width and a coefficient of 0.75 as adopted by (Stickler et al., 1961). Leaf area index (LAI) was calculated by dividing leaf area by land area subtending the plants to obtain LAI (Radford, 1967). At the hysiological maturity, plant height and grain/seed yield of sweet sorghum and legumes were recorded from four-meter long row section from both intercrop and sole crop. Plant height was recorded from the ground level up to the upper most point of the plant. Grain and seed moisture contents were first determined on dry weight basis and finally converted to 12 % moisture content for sweet sorghum and 10 % moisture content for both mung bean and soybean. The land equivalent ratio (LER) of intercropping patterns was computed according to Willey (1979).

Nutritional status computation

The total carbohydrate, protein and fat and energy outputs of sweet sorghum, mung bean and soybean were calculated for sole crops and intercropping using published information: carbohydrate content of sweet sorghum, mung bean and soybean at 12.0, 9.0 and 9.5 % moisture contents in grains, respectively was 70.7, 62.6 and 30.2 g, respectively; protein content was 10.4, 23.9 and 36.5 g, respectively; and fat content of 3.1, 1.2 and 19.9 g, respectively, per 100 g seed weight (FAO, 1995; USDA, 2011). The digestible energy content in carbohydrate, protein and fat was 17, 16 and 37 kJ g^{-1} of dry weight, respectively (Potter, 1978; Bender, 2005). Total energy output of the sole crop of sweet sorghum and intercropping patterns was calculated taking into consideration the total outputs of carbohydrate, protein and fat.

Table 5. Grain yield of sweet sorghum, seed yield of legumes and land equivalent ratio (LER) of sweet sorghum-mung bean and sweet sorghum-soybean intercropping during dry and wet seasons 2009-2010.

Treatment	Dry season					Wet season				
	Grain yield, t ha^{-1}	Seed yield, t ha^{-1}		LER		Grain yield,t ha^{-1}	Seed yield, t ha^{-1}		LER	
	Sweet sorghum	Mung bean	Soybean	Mung bean	Soybean	Sweet sorghum	Mung bean	Soybean	Mung bean	Soybean
Sole crop[1/]	5.4 ± 0.3	1.8 ± 1.1	1.7 ±0.4	-	-	5.4±0.7	1.5±0.2	1.3±0.2	-	-
Intercropping										
Type of legume										
Mung bean	5.1 ± 0.4	0.9 ±0.4	-	1.5	-	4.1±0.5	1.2±0.09	-	1.5	-
Soybean	5.4 ± 0.4	-	1.2±0.4		1.7	4.9±0.6	-	1.1±0.2	-	1.6
LSD (P=0.05)	0.1	-	-	0.2[2/]	0.2		-	-	0.1	
Planting pattern[3/]										
ASR	5.3 ± 0.4	0.6 ±0.1	1.0±0.2	1.3	1.6	4.7±0.6	1.2±0.1	1.1±0.2	1.7	1.7
ADR	5.2 ± 0.4	1.3 ±0.7	1.5±0.5	1.7	1.8	4.4±0.5	1.3±0.2	1.2±0.1	1.7	1.7
LSD (P=0.05)	0.1	0.8	0.4	0.2	0.2	0.2	ns[4/]	ns	ns	ns
Time of seeding										
Simultaneous	5.1 ± 0.4	0.6 ±0.1	1.0±0.4	1.3	1.5	4.3±0.6	1.1±0.1	1.0±0.1	1.5	1.6
Staggered	5.4 ± 0.7	1.3 ±0.7	1.5±0.3	1.7	1.9	4.7±0.5	1.4±0.2	1.2±0.3	1.8	1.8
LSD (P=0.05)	0.1	0.8	0.4	0.2	0.2	0.2	0.1	0.2	0.1	0.1
CV, %	1.2	55.1	18.2	11.1	11.1	5.4	7.8	10.6	6.4	6.4

1/ Yield of sweet sorghum and legume in sole cropping is shown for comparison with intercropping; 2/ LSD value applicable for the difference in LER between mung bean and soybean 3/ ASR – Alternate single rows; ADR – Alternate double rows; 4/ ns – Not significant at p=0.05;

Table 6. The effect of legume type, planting pattern and time of seeding on output of carbohydrate, protein, fat and energy in intercropping patterns of dry and wet seasons 2009-2010

Treatment	Dry season				Wet season			
	Carbohydrate,t ha^{-1}	Protein,t ha^{-1}	Fat,t ha^{-1}	Energy,MJ ha^{-1}	Carbohydrate,t ha^{-1}	Protein,t ha^{-1}	Fat,t ha^{-1}	Energy,MJ ha^{-1}
Sole crop[1/]	3.80 ± 0.20	0.60 ± 0.03	0.20± 0.01	80.7 ± 4.50	3.83 ± 0.51	0.53 ± 0.06	0.17 ± 0.06	80.03 ± 10.66
Intercropping								
Type of Intercrop								
Mung bean	4.19 ± 0.36	0.75 ± 0.09	0.17 ± 0.01	89.50 ± 7.90	3.65 ± 0.40	0.72 ± 0.07	0.14 ± 0.02	78.37 ± 8.53
Soybean	4.18 ± 0.27	1.01 ± 0.12	0.41 ± 0.07	102.70 ± 7.40	3.85 ± 0.49	0.92 ± 0.13	0.38 ± 0.05	94.00 ± 12.26
LSD (P=0.05)	ns[3/]	0.10	0.04	0.79	0.15	0.03	0.02	3.10
Planting pattern[2/]								
ASR	4.06 ± 0.24	0.79 ± 0.04	0.26 ± 0.02	78.50 ± 5.70	3.83 ± 0.46	0.82 ± 0.10	0.26 ± 0.04	87.57 ± 10.86
ADR	4.31 ± 0.39	0.97 ± 0.17	0.31 ± 0.06	77.20 ± 6.00	3.66 ± 0.43	0.82 ± 0.10	0.26 ± 0.03	84.80 ± 9.94
LSD (P=0.05)	0.23	0.10	0.04	0.79	0.15	ns	ns	ns
Time of seeding								
Simultaneous	3.89 ± 0.27	0.76 ± 0.08	0.32 ± 0.05	75.30 ± 6.30	3.56 ± 0.47	0.76 ± 0.08	0.24 ± 0.03	81.33 ± 10.21
Staggered	4.48 ± 0.36	1.00 ± 0.13	0.25 ± 0.03	80.40 ± 5.40	3.94 ± 0.43	0.88 ± 0.12	0.28 ± 0.04	91.04 ± 10.59
LSD (P=0.05)	0.23	0.10	0.04	0.79	0.15	0.03	0.02	3.10
CV, %	6.4	13.2	17.0	1.2	4.3	5.0	9.1	4.2

1/ Value of each parameter of sweet sorghum sole crop is shown for comparison with intercropping; 2/ ASR – Alternate single rows; ADR – Alternate double rows; 3/ ns – Not significant at p=0.05.

Data analysis

The analysis of variance was performed for data taking into consideration seasonal effects. In situations with significant seasonal effects, data were treated within each season separately. Orthogonal contrast procedure was adopted to compare the performance of crops in sole and intercropping stands. Fisher's Protected Least Significant Difference Procedure was used to compare the treatment means and interaction effects (Steel and Torrie, 1980).

Conclusions

This study revealed advantages of intercropping sweet sorghum with legumes compared to sole cropping. Establishment of component crops in the ASR pattern proved superior to the ADR pattern. On the other hand, the ADR pattern provided a greater opportunity for the legume to perform well compared to the ASR pattern. Staggered seeding created a competition-reduced environment for the legumes to flourish its vegetative growth compared to simultaneous seeding. Therefore, intercropping sweet sorghum with soybean in ASR pattern and staggered seeding interactively reduced the competition between component crops and enhanced crop productivity, land equivalent ratio (LER) and nutritive values.

Acknowledgments

Authors acknowledge the financial assistance by Higher Education Commission (HEC) of Pakistan and Agricultural Systems and Engineering field of study of the Asian Institute of Technology (AIT), Thailand.

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