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CROP PRODUCTION AND MANAGEMENT - Article

Spatio-temporal reconciliation to lessen losses in yield and quality of forage soybean (*Glycine max* L.) in soybean-sorghum intercropping systems

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ABSTRACT: Soybean suffers a serious blow to forage yield and quality while in intercropping with cereal forages like sorghum. The aim of this field investigation was to optimize planting time and spatial arrangement for boosting yield, quality and profitability of intercropped soybean. Treatments included soybean sown 20 days before and after sorghum under different spatial arrangements (3-1, 1-3, 2-3, 3-2 and 3-3 row proportions). The factorial arrangement was used to employ randomized complete block design (RCBD) for experimental execution with four replicates. Soybean sown 20 days prior to sorghum in 2-3 row replacement series was effective in yielding the highest yield attributes of soybean, which led to the highest green forage yield and dry matter biomass. The same intercropping system proved to be superior in generating the highest net income and benefit-cost ratio (BCR) (4.31). Correlation analysis revealed a positive correlation between agronomic variables under study and forage yield of soybean. Better quality forage with significantly higher crude protein, ether extractable fat and ash along with the lowest crude fiber content was given by soybean planted 20 days before sorghum in 3-2 row proportion. Soybean sown 20 days after sorghum under all spatial arrangements did not perform at par with soybean sown 20 days before sorghum. Thus, in order to avoid the drastic effects of sorghum on soybean forage yield and quality in soybean-sorghum intercropping systems, deferred sowing of sorghum might be considered keeping in view the availability of irrigation water and available time with respect of next crop.

Key words: *Glycine max*, agronomic management, animal nutrition, row-replacement series, *Sorghum bicolor*.

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INTRODUCTION

Skyrocketing demand for animal-based food and rising livestock population are making it pertinent to increase supplies of quality forage on sustainable basis. Cereal forages like sorghum can provide abundant quantities of green forage during summer months, but dairy animals fed on forage sorghum need protein and energy rich concentrates to make up for protein deficiency (Iqbal et al. 2015). Sorghum-soybean intercropping has been reported as one of the biologically and economically feasible options to increase the productivity and quality of forage. Soybean (*Glycine max* L.), also famous by the name of golden bean, has witnessed a long and steady history as a forage crop sown alone or in association with cereal forages until the trend shifted it to be grown as beans (Rao et al. 2005; Ghosh et al. 2006a). Soybean is a rich source of plant protein and its inclusion in animal's feed reduces the need to supplement lactating animals with concentrates. Soybean, being a leguminous crop, has the ability to fulfill a greater proportion of nitrogen requirement through nitrogen fixation process, taking place in root nodules with the help of soil bacteria, namely, *Bradyrhizobium japonicum* (Acikgoz et al. 2008). Fixed nitrogen not only improves vegetative growth of soybean but also gets transferred to cereal crops through roots intermingling in soybean based intercropping systems (Sheaffer et al. 2001).

However, soybean suffers a huge loss in forage yield and quality owing to shading effect rendered by cereal forages, including sorghum in soybean-cereals intercropping systems (Iqbal et al. 2016). Furthermore, the same pool of growth resources, including moisture and nutrients, is utilized by both component crops, especially at earlier growth stages, which results in sharp decline of their respective share (Ahmad et al. 2007). Nevertheless, in contrast to soybean, sorghum is expected to get advantage at latter growth stages, when the root nodules of soybean become fully functional and start fixing nitrogen, resultantly, sorghum can get more share of nitrogen from soil solution (Iqbal et al. 2015).

The type of intercropping (row replacement or mixed) could determine the productivity and performance of soybean based intercropping systems. Spatial arrangements could be another factor influencing the complementary or competitive nature of relationship among component crops by affecting utilization efficacy of farm-applied resources as well as environmental resources, including solar radiation. Along with spatial arrangements, the same planting time of component crops was found to causes an increase in the degree of competition for growth resources, which ultimately led to significant reduction in the growth and development of component crops (Seiter et al. 2004; Agegnehu et al. 2006).

It was hypothesized that delaying the sowing of one of the component crops instead of their simultaneous sowing could increase forage yield. Furthermore, there was another hypothesis that certain spatial arrangements could reduce the drastic effects of sorghum on soybean forage in soybean-sorghum intercropping systems. Thus, the present study was aimed to lessen the losses in soybean forage yield and quality deterioration while in intercropping with forage sorghum through optimization of different spatial arrangements and sowing time. Another objective of this field trial was to increase the economic returns of soybean by increasing forage yield and benefit to cost ratio.

MATERIAL AND METHODS

The experiment was conducted in Faisalabad (Pakistan) having soil of Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid (USDA soil classification) and Haplic Yermosols (FAO classification scheme) (Naeem et al. 2013). Composite samples were prepared from subsamples collected from 30, 45 and 60 cm depth and then homogenized to determine the physico-chemical properties of the experimental soil for proper fertilization and to formulate appropriate agronomic management plan. Sandy clay loam was the textural class of the experimental soil and was severely deficient in nitrogen and phosphorous along with organic matter. The pH of the experimental soil remained between 7.7 – 7.9 during all three years (Table 1). The climate of experimental area is classified as semi-arid (Koppen-Geiger classification). The mean daily temperature remained 40.6 – 41.7 °C during the crop growing seasons, while total precipitation of growing seasons was 141 – 174 mm as per data recordings of agro-meteorological observatory just located away from our experimental fields. A comparison of precipitation, temperature and relative humidity of crop growing seasons of experimental years with 10 years average data are depicted in Table 2.

Table 1. Pre-sowing physico-chemical analysis of experimental soil (Faisalabad, Pakistan) from composite samples taken at 30, 45 and 60 cm depth, in 2013, 2014 and 2015.

Soil characteristics	Values (Average of three soil layers)		
Mechanical analysis	2013	2014	2015
Sand (%)	59	58	58
Silt (%)	19.3	18	18.5
Clay (%)	21.7	24	23.5
Textural class	Sandy clay loam	Sandy clay loam	Sandy clay loam
Chemical analysis	2013	2014	2015
pH	7.8	7.7	7.9
EC (dSm^{-1})	1.53	1.50	1.52
Organic matter (%)	0.65	0.67	0.68
Total nitrogen ($mg{\cdot}kg^{-1}$)	326.0	357.9	369.3
Available phosphorous ($mg{\cdot}kg^{-1}$)	6.2	6.5	6.7
Available potassium ($mg{\cdot}kg^{-1}$)	191.1	187.6	198.2

Table 2. Monthly precipitation (total), mean temperature and relative humidity of experimental site (Faisalabad, Pakistan) during crop growing seasons of 2013, 2014 and 2015 along with last 10 years mean data (10YsM).

Month	Precipitation (mm)				Temperature (°C)				Relative humidity (%)			
	2013	2014	2015	10YsM	2013	2014	2015	10YsM	2013	2014	2015	10YsM
May	40	31	27	33.5	38.5	39.7	39.1	38	64	59	61	60
June	30	21	24	23.3	41.0	41.5	42.4	40.1	57	62	60	64
July	104	98	90	90.9	42.4	43	43.7	40.9	71	68	65	69
Total/Mean	174	150	141	146	40.6	41.4	41.7	39.6	64	66.3	62	64.3

There were two factors including two planting times (soybean planted 20 days before sorghum, soybean planted 20 days after sorghum) and five spatial arrangements (soybean-sorghum row proportions of 3-1, 1-3, 2-3, 3-2 and 3-3). In this way, experiment was comprised of total 10 treatments per experimental unit, while the number of experimental units was 40. The experiments were carried out in factorial arrangements of randomized complete block design (RCBD) with four replicates. The (net) plot size was kept at 6.0 × 4.0 meters, while there were 20 rows in each experimental unit.

The agronomic management plan was kept same for all experimental units. For proper seed bed preparation, a pre-sowing irrigation of 12 cm was given and when the soil had attained an appropriate moisture level, tractor mounted cultivator was used thrice for proper cultivation. Light planking followed each cultivation to achieve good soil tilth for appropriate soil-seed interaction. Soybean (cv. Ajmeri) was sown in association with forage sorghum (cv. JS-2002) using a seed rate of 100 $kg{\cdot}ha^{-1}$, while the seed rate of sorghum was 75 $kg{\cdot}ha^{-1}$. Seeds were treated with fungicide (benlate at the rate of 2 $g{\cdot}kg^{-1}$ of seed) to avoid the occurrence of fungal attack. The sowing of soybean was done with the help of a single row cotton drill in 30 cm spaced rows, while no consideration was given to plant-to-plant distance. Single super phosphate [$Ca(H_2PO_4)_2 + CaSO_4$] was used as the source of phosphorous and was applied at the rate of 60 $kg.ha^{-1}$ in a single dose at the time of sowing, while nitrogen was applied in the form of urea [$(NH_2)_2CO$] at the rate of 80 $kg.ha^{-1}$ in two equal splits. Three irrigations (3 acre inches each) through flood irrigation were applied at second trifoliate, fifth trifoliate and flower initiation growth stages of soybean. Weed infestation was kept below threshold level by three manual hoeing at 10, 22 and 36 days after sowing. Soybean was harvested at 50% flowering stage with the help of hand sickle.

Ten randomly selected plants from each replication were used to record experimental variables and then average of four replications was used to statistically analyze and interpret the recorded data. Plant height of soybean was recorded from base to top and was averaged. Stem girth was also recorded from three points including base, mid and top of the stem with the help of vernier caliper and then their average was taken for statistical analysis. Crude protein, crude fiber, either extractable fat and total ash of soybean forage were also determined using standard techniques as prescribed by AOAC (2000). To determine the economic feasibility of soybean based intercropping systems, partial budgeting technique was used. As soybean was sown as a component crop with forage sorghum, thus only half of the fixed costs and full of variable costs were counted for soybean. Gross income was computed by multiplying forage yield ($t{\cdot}ha^{-1}$) with local market rate ($US\${\cdot}ton^{-1}$) of forage. Net income was determined by deducting the total expenditure from the gross income. Benefit to cost ratio (BCR) was also calculated to determine economic returns by using the Eq. 1 (CIMMYT 1988):

$$BCR = \text{Gross income} / \text{Total cost} \quad (1)$$

Data for all experimental variables under study were subjected to analysis of variance (ANOVA) using the computer based statistical program SAS 9.5. The F-test was employed to determine the effects of planting time (P), spatial arrangements (SA) and year (Y), along with their interactive effects (P × SA, P × Y, SA × Y, P × SA × Y) at 5% and 1% probability levels. Duncan's multiple range test ($p \leq 0.05$) was used to separate treatment means and correlation analysis was also performed in order to establish the nature of relationship (linear or inverse) between growth parameters and green forage yield of soybean.

RESULTS AND DISCUSSION

All intercropping systems significantly affected yield components and forage yield of soybean sown with forage sorghum under different planting times and spatial arrangements during all three years. All agronomic experimental variables underwent a significant influence of planting time ($p \leq 0.01$) and spatial arrangements ($p \leq 0.05$) (Table 3). Plant height and stem girth are important yield components and contribute positively towards green forage yield of soybean. Soybean sown 20 days before sorghum in 2-3 row proportion (P_1SA_3) resulted in the tallest soybean plants (80.0 cm) with the highest stem girth (3.79 cm) along with yielding the greatest number of leaves (19.3) and branches (6.00) per plant (Table 4).

Deferred sowing of soybean for 20 days under all spatial arrangements caused a significant reduction of growth parameters, while the minimum growth was registered for soybean planted 20 days after sorghum in 1-3 row replacement series (P_2SA_2). Furthermore, green forage yield was found to have linear relation with plant height (Figure 1a) and stem girth (Figure 1b) of soybean. These results are in contradiction with those of Addo et al. (2011), who reported that spatial patterns and time of planting were determining factors in maize-soybean intercropping systems. But it was also concluded that components crops needed to be sown at the same time in order to take the full benefit of intercropping. However, field studies conducted by Dapaah et al. (2003) reported that soybean growth was negatively affected in intercropping with →

Table 3. Analysis of variance for agronomic variables and agro-qualitative attributes of forage soybean at harvest as influenced by different planting times and spatial arrangements (pooled data of 2013, 2014 and 2015 with combined analysis).

	Significance of *F*-Values from analysis of variance											
Intercropping systems	PH (cm)	SG (cm)	NB	NL	FW (g)	DW (g)	GFY (t.ha-1)	(DMY (t·ha-1)	CP (%)	CF (%)	EEF (%)	TA (%)
Y	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P	**	**	**	**	**	**	**	**	**	**	**	**
Y × P	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SA	*	*	*	*	**	*	*	*	**	*	*	*
SA × Y	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P × SA	**	**	*	*	**	*	**	**	**	*	*	**
P × SA × Y	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*Significant at 0.05 level, ** Significant at 0.01 level, NS = Non-significant SOV = Source of Variance. Y = Year, P = Planting time, SA = Spatial Arrangements. PH = Plant Height, SG = Stem Girth, NB = Number of Branches per plant, NL = Number of Leaves per plant, FW = Fresh Weight, DW = Dry Weight, GFY = Green Forage Yield, DMY = Dry Matter Yield, CP = Crude Protein, CF = Crude Fiber, EEF = Ether Extractable Fat, TA = Total Ash.

Table 4. Agronomic variables of forage soybean at harvest as influenced by different planting times and spatial arrangements (pooled data of 2013, 2014 and 2015 with combined analysis).

Intercropping systems	PH (cm)	SG (cm)	NB	NL	FW (g)	DW (g)	GFY (t·ha⁻¹)	DMY (t·ha⁻¹)
P_1SA_1	73.9 ± 0.34bc	3.64 ± 0.22b	5.79 ± 0.64bc	15.3 ± 0.29c	72.4 ± 0.49d	15.52 ± 0.46b	13.6 ± 0.44d	5.81 ± 0.71c
P_1SA_2	71.8 ± 0.2c	3.66 ± 0.29b	5.71 ± 0.38c	16.1 ± 0.35b	75.1 ± 0.68c	17.81 ± 0.22a	13.4 ± 0.29d	5.79 ± 0.52c
P_1SA_3	80.0 ± 0.5a	3.79 ± 0.39a	6.00 ± 0.29a	19.3 ± 0.54a	85.8 ± 0.87a	17.86 ± 0.68a	20.1 ± 0.40a	6.20 ± 0.66a
P_1SA_4	76.1 ± 0.69b	3.77 ± 0.41a	5.96 ± 0.51ab	16.0 ± 0.24b	78.1 ± 0.66b	13.27 ± 0.54c	16.5 ± 0.35c	6.03 ± 0.38b
P_1SA_5	74.3 ± 0.73bc	3.52 ± 0.33c	5.88 ± 0.63b	15.1 ± 0.71c	78.6 ± 0.71b	13.21 ± 0.31c	17.5 ± 0.61b	5.96 ± 0.55bc
P2SA1	60.3 ± 0.55e	3.41 ± 0.48d	5.11 ± 0.54f	11.8 ± 0.66e	65.0 ± 0.76e	13.23 ± 0.45c	11.6 ± 0.59e	5.15 ± 0.49e
P_2SA_2	60.8 ± 0.59e	3.07 ± 0.21f	5.08 ± 0.42g	11.5 ± 0.30f	62.9 ± 0.55f	11.01 ± 0.57e	11.4 ± 0.76e	5.12 ± 0.34e
P_2SA_3	70.0 ± 0.44c	3.10 ± 0.51ef	5.47 ± 0.49d	12.4 ± 0.59d	72.0 ± 0.35d	13.29 ± 0.70c	13.3 ± 0.25d	5.45 ± 0.57d
P_2SA_4	69.4 ± 0.57c	2.97 ± 0.44f	5.30 ± 0.34e	12.2 ± 0.24d	73.6 ± 0.49d	12.19 ± 0.54d	11.8 ± 0.34e	5.17 ± 0.30de
P_2SA_5	63.9 ± 0.50d	3.13 ± 0.38e	4.51 ± 0.70d	11.9 ± 0.60e	64.5 ± 0.42e	12.93 ± 0.44d	11.7 ± 0.64e	5.13 ± 0.67e

*Significant at 0.05 level, ** Significant at 0.01 level, NS = Non-significant. PH = Plant Height, SG = Stem Girth, NB = Number of Branches per plant, NL = Number of Leaves per plant, FW = Fresh Weight, DW = Dry Weight, GFY = Green Forage Yield, DMY = Dry Matter Yield. P_1 = Soybean sown 20 days before sorghum, P_2 = Soybean sown 20 days after sorghum, SA_1 = Soybean-sorghum sown in 3-1 row proportion, SA_2 = Soybean-sorghum sown in 1-3 row proportion, SA_3 = Soybean-sorghum sown in 2-3 row proportion, SA_4 = Soybean-sorghum sown in 3-2 row proportion, SA_5 = Soybean-sorghum sown in 3-3 row proportion.

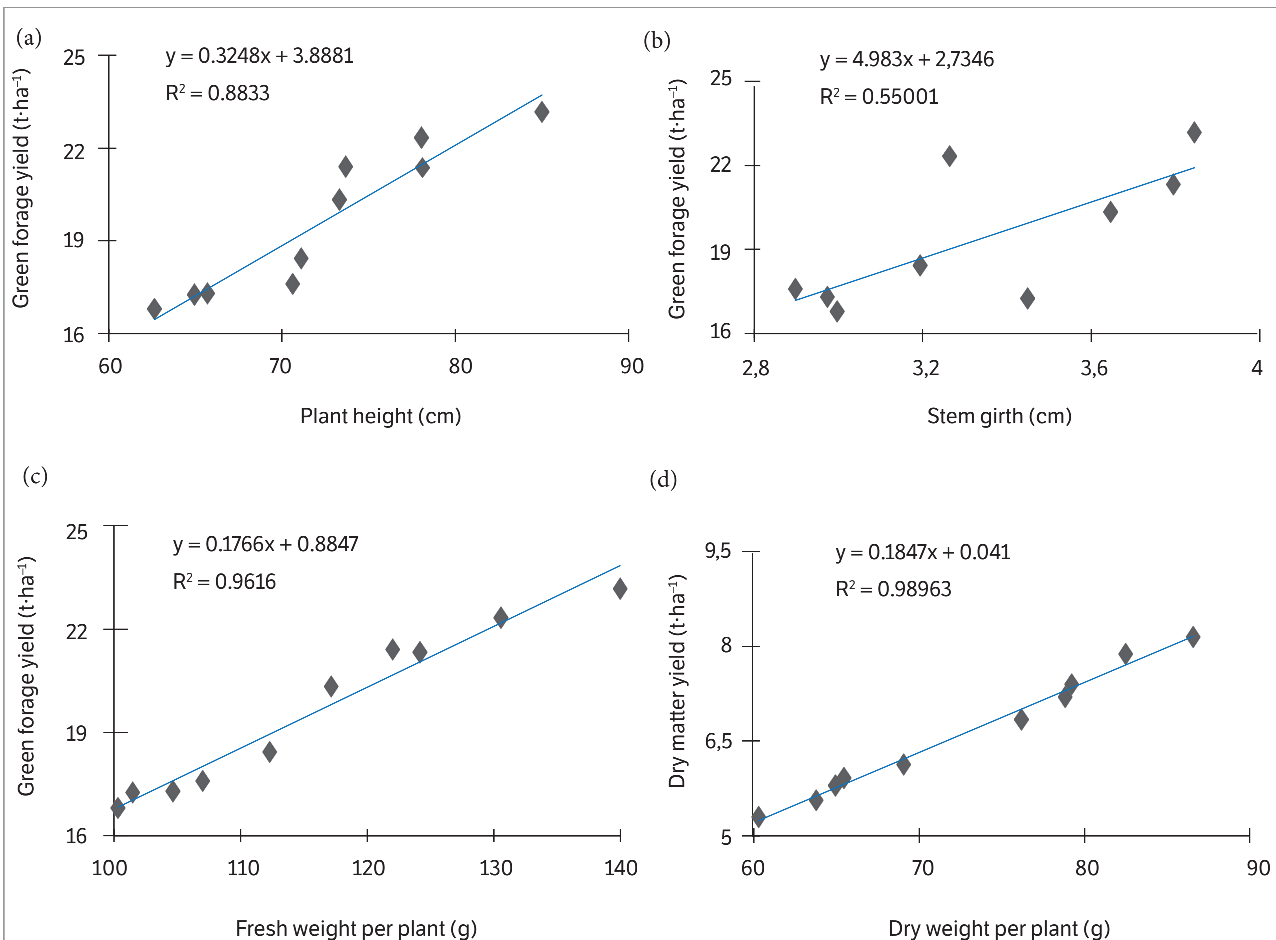

Figure 1. Correlation analysis for (a) plant height and green forage yield, (b) stem girth and green forage yield, (c) fresh weight per plant and green forage yield, (d) dry weight per plant and dry matter yield of soybean sown with sorghum under different planting times and spatial arrangements (pooled data of 2013, 2014 and 2015 with combined analysis).

cereal forages due to higher population pressure over limited growth resources. It was further revealed that plant height and stem girth were found to have direct relationship with green forage yield of soybean as comparatively higher green forage yield of soybean was recorded in plots where there were significantly taller soybean plants with higher stem girth. These findings also closely corroborate with the conclusions made by Arshad et al. (2006), who stated that sole cultivation of soybean resulted in better growth and development of soybean plants, which resulted in increased yield. However, in our research, earlier sowing of soybean for 20 days and 2-3 row proportion of soybean-sorghum provided soybean more space and reduced the shading effect, which led to better growth and development of soybean.

Earlier sowing of soybean gave higher fresh weight (130.7 g) and dry weight (41.1 g) per plant, which led to significantly higher green forage yield and dry matter biomass, while delayed sowing of soybean witnessed a considerable reduction in green forage yield and dry matter. It was further revealed that fresh weight (Figure 1c) and dry weight (Figure 1d) per plant of soybean were linearly correlated with green forage yield and dry matter biomass, respectively. Gare et al. (2009) and Hintz and Albrecht (1994) also reported the same findings, where dry weight per plant of soybean was proved to be a reliable indicator for projecting dry matter yield of soybean, as dry matter biomass was increased with increasing dry weight per plant and same was found to be true for intercrops.

The performance of forage component crops in cereal-legumes intercropping systems is reflected by biomass production on per unit basis. Soybean recorded the highest green forage yield (20.1 $t \cdot ha^{-1}$) and dry matter yield (6.2 $t \cdot ha^{-1}$) (Table 4), when it was sown in 2-3 row proportion and sorghum planting was deferred for 20 days (P_1SA_3). Earlier sowing of soybean for 20 days in 3-2 row replacement series followed this intercropping system, while soybean sown 20 day after sorghum in 1-3 row replacement series (P_2SA_2) yielded the lowest green forage yield and dry matter yield of soybean. Soybean sowing in 2-3 row replacement series and deferred sowing of sorghum for 20 days recorded the highest yield components, like plant height, stem girth, number of branches and leaves per plant, along with the highest fresh weight and dry weights per plant of soybean, which ultimately led to significantly higher green forage yield and dry matter yield of soybean. Soybean intercropping with cereal forages at the same time might result in increased population pressure on divisible moisture and nutrients pool, and ultimately decreased share of vital growth inputs, resulting in decreased forage yield of soybean soybean-sorghum intercropping systems (Li et al. 2001). Prior field investigation of Dapaah et al. (2003) also confirm these findings as they also found that yield stability of component crops, including soybean, hit a setback while in intercropping with cereal forages in comparison with their sole sowing because of severed soil-supplied resources along with shading effect of taller cereal plants.

One of the major objectives of cereal-legumes intercropping systems is the enhancement of forage quality, particularly protein content, therefore, it is pertinent to monitor and analyze quality attributes of legumes in intercropping systems. Soybean sown 20 days prior to sorghum in 3-2 row replacement series (P_1SA_4) remained outstanding in terms of crude protein contents (20.88%), along with highest ether extractable fat (1.91%) and ash (11.32%) (Table 5), and it was closely followed by soybean sown 20 days prior to sorghum in 3-3 row proportion (P_1SA_5). The same intercropping system (P_1SA_4) was effective in decreasing the crude fiber contents (28.11%), while soybean sown 20 days after sorghum in 1-3 row replacement series (P_2SA_2) recorded the highest crude fiber content. As there has been reported a direct and linear relationship between nitrogen supplies and protein contents of forages, thus soybean sown 20 days prior to sorghum in 3-2 row proportion allowed soybean to absorb more nitrogen from soil solution along with greater quantities of nitrogen fixed through biological nitrogen fixation process, which helped soybean to produce comparatively higher crude protein and relatively lower crude fiber (Ghosh et al. 2006b). It has also been reported that increase in crude protein decreased crude fiber contents in different forages (Acikgoz et al. 2008; Ghosh et al. 2009). Sorghum-soybean intercropping at different times allows component crops to exploit different soil horizons due to varied root length, which ultimately ended up in better quality forage due to higher quantities of nitrogen absorbed by both cereals and soybean crops (Nielsen 2011). Thus, by delaying sorghum sowing for 20 days provided soybean a competition free environment as that of pure stand of soybean and resultantly better quality forage was obtained.

As all the farming operations and activities revolve around economics and same is the matter of forage production, thus economic analysis is of utmost importance in order to analyze the productivity and profitability of soybean based intercropping systems. The highest net income and benefit-cost ratio was rendered by soybean sown 20 days prior to sorghum in 2-3 row replacement series which, was followed by soybean planted 20 days before sorghum in 3-2 row replacement series, which in turn was followed by soybean sown 20 days prior to sorghum in 3-3 row ratio (Table 6). Soybean sown 20 days after sorghum in 3-1 row replacement series recorded the lowest BCR of 2.84 (Table 6). Prior research findings reported by Mucheru-Muna et al. (2010) also support our research results where legumes yield and economic returns witnessed a significant decline when cereal and legumes were intercropped at the same time under different spatial arrangements. It was also reported similar findings where yield of component crops were decreased in cereal-legumes intercropping systems but overall productivity per unit land area was increased to a great extent and ultimately net income and BCR were increased.

Thus, the findings of this research offer a feasible, eco-friendly and economical solution to increase the share of soybean in soybean-sorghum intercropping systems by deferring the sowing of forage sorghum for 20 days. This research might be applicable to other legumes intercropped with cereal forages for reducing →

Table 5. Agro-qualitative attributes of forage soybean at harvest as influenced by different planting times and spatial arrangements (pooled data of 2013, 2014 and 2015 with combined analysis).

Intercropping systems	CP (%)	CF (%)	EEF (%)	TA (%)
P_1SA_1	20.54 ± 0.67c	28.64 ± 0.51d	1.81 ± 0.34bc	11.02 ± 0.66c
P_1SA_2	20.58 ± 0.39bc	28.53 ± 0.92e	1.77 ± 0.61c	11.00 ± 1.17c
P_1SA_3	20.56 ± 0.41c	28.72 ± 0.37c	1.81 ± 0.14bc	11.04 ± 0.94bc
P_1SA_4	20.88 ± 0.15a	28.11 ± 0.43f	1.91 ± 0.28a	11.32 ± 0.34a
P_1SA_5	20.60 ± 0.67b	27.20 ± 0.39g	1.84 ± 0.11b	11.08 ± 0.58b
P_2SA_1	20.31 ± 0.39d	29.25 ± 0.57ab	1.73 ± 0.55c	10.86 ± 0.92d
P_2SA_2	20.00 ± 0.45f	29.07 ± 0.32b	1.58 ± 0.38e	10.80 ± 0.50e
P_2SA_3	20.14 ± 0.37e	29.35 ± 0.29a	1.69 ± 0.27cd	10.86 ± 0.44de
P_2SA_4	19.94 ± 0.66fg	29.29 ± 0.81ab	1.74 ± 0.46c	10.92 ± 0.34d
P_2SA_5	20.26 ± 0.31d	28.55 ± 0.22e	1.65 ± 0.15d	10.79 ± 0.12e

*Significant at 0.05 level, ** Significant at 0.01 level, NS = Non-significant, CP = Crude Protein, CF = Crude Fiber, EEF = Ether Extractable Fat, TA = Total Ash. P_1 = Soybean sown 20 days before sorghum, P_2 = Soybean sown 20 days after sorghum, SA_1 = Soybean-sorghum sown in 3-1 row proportion, SA_2 = Soybean-sorghum sown in 1-3 row proportion, SA_3 = Soybean-sorghum sown in 2-3 row proportion, SA_4 = Soybean-sorghu sown in 3-2 row proportion, SA_5 = Soybean-sorghum sown in 3-3 row proportion.

Table 6. Gross income, net income and benefit-cost ratio (BCR) of forage soybean as influenced by different planting times and spatial arrangements (pooled data of 2013, 2014 and 2015 with combined analysis).

Intercropping systems	Total expenditures (Fixed + Variable) (US$)	Gross income (US$)	Net income (US$)	BCR
P_1SA_1 = Soybean sown 20 days before sorghum in 3-1 row proportion	137+45=182	642.35	460.00	3.52
P_1SA_2 = Soybean sown 20 days before sorghum in 1-3 row proportion	137+15=152	608.70	456.70	4.00
P_1SA_3 = Soybean sown 20 days before sorghum in 2-3 row proportion	137+24=161	694.82	533.80	4.31
P_1SA_4 = Soybean sown 20 days before sorghum in 3-2 row proportion	137+36=173	669.90	496.90	3.87
P_1SA_5 = Soybean sown 20 days before sorghum in 3-3 row proportion	137+30=167	639.00	472.00	3.82
P_2SA_1 = Soybean sown 20 days after sorghum in 3-1 row proportion	137+45=182	517.80	335.80	2.84
P_2SA_2 = Soybean sown 20 days after sorghum in 1-3 row proportion	137+15=152.	504.00	352.00	3.31
P_2SA_3 = Soybean sown 20 days after sorghum in 2-3 row proportion	137+24=161	552.30	391.30	3.43
P_2SA_4 = Soybean sown 20 days after sorghum in 3-2 row proportion	137+36=173	528.13	355.00	3.05
P_2SA_5 = Soybean sown 20 days after sorghum in 3-3 row proportion	137+30=167	519.60	352.60	3.11

the drastic effects of dominant cereals on leguminous forages. Furthermore, these findings will be beneficial to other researchers as a reference and will explore new research horizons in cereal-legumes intercropping for obtaining higher productivity and quality of mixed forage in comparison with their sole cropping. As in our study, though deferred sowing of sorghum for 20 days proved to be effective in increasing soybean productivity, there is a need to test earlier sowing of soybean for lesser or greater than 20 days along with other row replacement series, which might be useful in getting even higher productivity and profitability.

CONCLUSION

It was hypothesized that losses in forage yield and quality deterioration of soybean in soybean-sorghum intercropping systems might be avoided by varying planting time of component crops and by optimizing spatial arrangements. We were successful to a great extent as soybean yielded reasonably higher green forage yield with improved quality attributes when sorghum sowing was deferred for 20 days and 2-3 row replacement series was adopted for soybean and sorghum intercropping. The same planting time and spatial arrangement was instrumental in generating the highest net income and benefit-cost ratio (BCR), while deferred sowing of soybean for 20 days reduced forage yield along with net income and BCR under all spatial arrangements. Thus, if irrigation water is available or soil moisture conditions in arid areas may support delayed sowing of sorghum then soybean earlier sowing has the potential to increase its share in mixed forage, which is bound to increase quality traits of mixed forage.

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