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AGRO-BOTANICAL RESPONSE OF FORAGE SORGHUM-SOYBEAN INTERCROPPING SYSTEMS UNDER ATYPICAL SPATIO-TEMPORAL PATTERN

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Abstract

Forage sorghum is a climate smart crop having drought, heat and salinity tolerance but its forage yield is not sufficient to meet forage requirement during summer months. Sorghum-soybean intercropping is a way to increase productivity but reduction in the yield of component crops owing to severe competition continues to remains a biggest challenge. A multi-year field trial was executed to assess the productivity of sorghum-soybean intercropping systems sown at varied times (sorghum and soybean sown simultaneously, sorghum sown 18 days prior to soybean and vice versa) and spatial arrangements (sorghum-soybean sown in 4:1, 4:4, 2:1 and 2:2 row proportions). Factorial arrangement of randomized complete block design was used to conduct the field trials with four replicates. Agronomic variables of forage sorghum (plant height, stem diameter, number of leaves, plant leaf area, fresh and dry weights per plant) were positively affected when it was sown 18 days earlier to soybean in 2:1 row proportion. The same intercropping system gave significantly (p<0.01) higher green forage yield, dry biomass of sorghum along with mixed (sorghum+ soybean) green forage yield and dry biomass yield. However, soybean green and dry biomass yields remained unmatched when it was sown 18 days earlier to sorghum in 2:1 row proportion. Thus, delayed sowing of one of the intercrops for 18 days has the potential to yield higher forage of component crops and this type of intercropping might be suggested depending upon the availability of irrigation water and its fitness into the prevailing cropping system.

Key words: Component crops; Deferred sowing; Forage productivity; Planting geometries; Row intercropping.

Introduction

Forages are considered to be the most palatable, economical and nutritious animal feed resource for livestock particularly for dairy animals (Ibrahim *et al*., 2012; Iqbal & Iqbal, 2015). Among cereal forages, sorghum (*Sorghum bicolor* L.) has attained a special attention in recent times (Oseni & Aliyu, 2010). Sorghum belongs to famous family of Poaceae and was deemed to be the crop of arid areas but emerging worrisome scenario of severe water shortage for agricultural purposes (Promkhambut *et al*., 2010) has made sorghum a good alternate forage crop for irrigated tracts of the world as well. There are a score of advantages associated with forage sorghum in contrast to forage maize including its drought and heat resistance potential. Sorghum being a C4 crop thrives well in scorching heat of sun and has resistance against drought, water logging and salinity along with other soil toxicities (Omari & Nhiri, 2015). Despite all these advantages, forage sorghum continues to remain under-utilized and farmers are not getting forage yield according to the potential of forage sorghum.

Intercropping of forage sorghum with legumes can be a way to increase green forage yield of sorghum with improved agro-qualitative attributes. Intercropping which is the practice of sowing two or more crops at the same time on the same piece of land holds numerous advantages. Traditionally this system of cropping is aimed to avoid dependence on a single crop, obtain a variety of products from the same piece of land, to improve the efficiency of available resources (Iqbal *et al.*, 2016) and to increase monetary benefits from small land holdings. Other major aims of intercropping are to increase the total productivity per unit area and time besides equitable and judicious utilization of land resources like water, solar radiation and farming inputs including labor (Marer *et al*., 2007). Thus sorghum-legumes intercropping systems intensify and diversify the cropping systems. The compatibility of component crops in intercropping systems is one of the important things that need to be kept in consideration.

Soybean (*Glycine max* L.) forage contains considerably higher protein to dairy animals and that too with reasonably higher digestibility (Akunda, 2001). Soybean yields green forage similar in quality to that of alfalfa (Carruthers *et al*., 2000). Prior field investigations have reported a significant decrease in forage yield of component crops when those were sown at the same time in cereal-legumes intercropping systems (Ahmad *et al*., 2007: Arshad & Ranamukhaarachchi, 2012: Iqbal *et al*., 2015). Sorghum and legumes intercrops compete for same pool of growth resources and ultimately a significant reduction in their yield has been recorded in comparison with their pure stands. Deferred sowing of one of the component crops could be a way to decrease the loss in the yield of component crops. Different spatial arrangements also influence the growth and development of sorghum legume intercrops by altering the complimentary or competitive nature of component crops. But there is a little information available about the influence of spatial arrangements and sowing time on productivity of sorghum-soybean intercropping systems under varied agro-climatic conditions. Thus, it was hypothesized that with delayed sowing of one of the component crops along with optimization of spatial arrangements, considerably higher productivity per unit area could be obtained.

Therefore, this field study was executed with aims to explore the production potential of forage sorghum and soybean in row intercropping systems. The effect of deferred sowing of soybean on growth and forage yield of sorghum and vice versa was also tested. The ultimate aim of this field investigation was to develop a highly sustainable forage sorghum-soybean based intercropping system especially suitable for the small land holdings.

Materials and Methods

Experimental site: The field trials were executed at the Agronomic Experimentation Area of University of Agriculture Faisalabad, Pakistan during summer months of two consecutive years (2013 and 2014). The geographical coordinates of experimental site are 30.35-41.47° N and 72.08-73.40° E with an elevation of about 184 m above the sea level. The experimental soil was subjected to mechanical and chemical analysis by collecting soil samples from 30 and 60 cm depth which were homogenized to prepare composite representative samples. The textural class of experimental soil was sandy clay loam having alkaline nature with pH of 7.9 and 8 during 2013 and 2014 respectively. The detailed soil analysis for both years (2013 and 2014) is illustrated in Table 1. The data regarding weather conditions including precipitation, mean monthly temperature and relative humidity for crop growing period during both years was taken from the record of meteorological observatory situated just away from our research fields (Fig. 1).

Table 1. Pre-sowing physico-chemical analysis of experimental soil.

Characteristics	Values	
Mechanical analysis	**2013**	**2014**
Sand (%)	60.0	58.0
Silt (%)	18.0	19.2
Clay (%)	22.0	22.8
Textural class	Sandy clay loam	Sandy clay loam
Chemical analysis	**2013**	**2014**
pH	7.9	8.0
EC (ds m^{-1})	1.51	1.53
Organic matter (%)	0.69	0.65
Total nitrogen (mg kg^{-1})	382.7	393.2
Available phosphorous (mg kg^{-1})	6.80	6.33
Available potassium (mg kg^{-1})	178.3	171.9

Experimental treatments and design: Following intercropping systems under varied planting times and geometries were tested;

T_1S_1= Sorghum and soybean simultaneously sown in 4:1 row proportion
T_2S_1= Sorghum and soybean simultaneously sown in 4:4 row proportion
T_3S_1= Sorghum and soybean simultaneously sown in 2:1 row proportion
T_4S_1= Sorghum and soybean simultaneously sown in 2:2 row proportion
T_1S_2= Sorghum sown 18 days prior to soybean in 4:1 row proportion
T_2S_2= Sorghum sown 18 days prior to soybean in 4:4 row proportion
T_3S_2= Sorghum sown 18 days prior to soybean in 2:1 row proportion
T_4S_2= Sorghum sown 18 days prior to soybean in 2:2 row proportion
T_1S_3= Soybean sown 18 days prior to sorghum in 4:1 row proportion
T_2S_3=Soybean sown 18 days prior to sorghum in 4:4 row proportion
T_3S_3= Soybean sown 18 days prior to sorghum in 2:1 row proportion
T_4S_3= Soybean sown 18 days prior to sorghum in 2:2 row proportion

Randomized Complete Block Design (RCBD) with factorial arrangement was used for executing the field trials with four replicates, while the net plot size was 3.6 m × 8.0 m. There were 12 rows in each experimental plot while there were total 48 experimental units (12 experimental plots per replication). The spacing between two rows was kept at 30 cm, while no consideration was given to plant × plant spacing as matter of principle for forage crops.

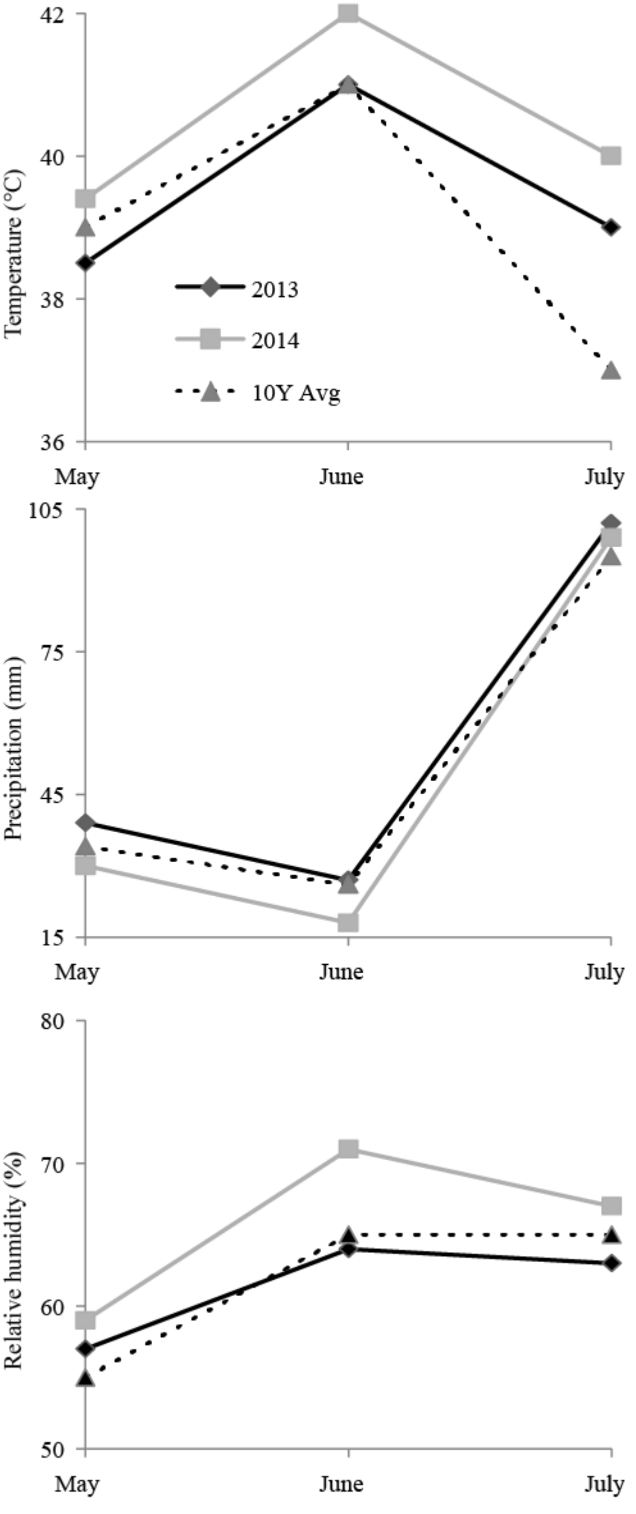

Fig. 1. Meteorological data for temperature, rainfall and relative humidity during crop growing seasons.

Agronomic management plan: An appropriate seedbed preparation with good soil tilth was achieved for all experimental plots which began with a pre-sowing irrigation of 12 cm. When soil had attained an appropriate moisture level, three cultivations (12 cm depth) using a tractor-driven cultivator were done while each cultivation was followed by planking using a tractor-driven wooden planker. Sowing of component crops was done with the help of single row hand (cotton) drill in 30 cm apart rows using a seed rate of 80 kg $ha^{-1}$of sorghum (cv. Hegari), while the seed rate of soybean (cv. Ajmeri) was 100 kg ha^{-1}. Recommended doses of fertilizers (100 kg N and 65 kg P_2O_5 ha^{-1}) were applied. At the sowing time, all of the phosphorous and half of nitrogen were applied while remaining nitrogen was applied in two equal splits with subsequent irrigations. It is worthy to mention here that no additional fertilizers were applied for intercrops. Three irrigations (7.5 cm) were given from sowing to harvesting of the component crops keeping in view the crop requirement and to avoid the onset of drought like conditions. The component crops were harvested 62 days after sowing when they reached to 50% heading stage with hand sickle.

Methodology for data recordings: Ten plants of sorghum were randomly selected from middle rows of experimental plots in each replication for measuring agronomic variables like plant height, stem girth, number of leaves/plant and leaf area/ plant etc. Plant height was recorded from base of the plant to the tip of the plant with the help of tailor's measuring tape. Stem diameter was determined from three portions (base, mid and top) using vernier caliper and then their average was calculated. Rests of the parameters were also recorded using prescribed methods and techniques (Iqbal *et al*., 2015a).

Statistical analysis: In order to perform the statistical analysis of the recorded data, Fisher's analysis of variance (ANOVA) technique was employed through a computer operated program "MSTAT-C" at the significance level of 0.05 and 0.01. The statistical analysis for interactive effect of planting times (T) and spatial arrangements (S) with year (Y) were also performed by using the same statistical program (Freed & Eisensmith, 1986). Regression analysis was performed to establish the sort of relationship between agronomic variables and forage yield of sorghum (Steel *et al.*, 1997).

Results and Discussion

The year effect on all agronomic parameters of forage sorghum was quite significant as there was more growth and development of forage sorghum during 2014 than the previous year. More favorable soil as well as weather conditions may be described as the possible reasons for this higher growth during 2014 as compared to 2013. Individual as well as interactive effect of planting times (p<0.01) and spatial arrangements (p<0.05) were significant in case of all agronomic parameters of forage sorghum. However, the interactive effects of planting time and spatial arrangements with year were non-significant (p>0.05) (Table 2). Regression analysis revealed a direct correlation of agronomic variables with green and dry matter yield of sorghum (Fig. 5).

Table 2. Analysis of variance (ANOVA) for experimental variables (combined analysis).

SOV	SD	PP	PH	SDi
S	78^{*}	109^{**}	263^{**}	145^{*}
T	64^{*}	88^{*}	181^{*}	97^{*}
S×T	71^{*}	96^{*}	255^{**}	124^{*}
SOV	**NL**	**LA**	**FW**	**DW**
S	144^{*}	301^{**}	284^{**}	212^{**}
T	84^{*}	189^{**}	143^{*}	101^{*}
S×T	123^{*}	288^{**}	265^{**}	142^{**}
SOV	**SGFY**	**SDMY**	**SoGFY**	**SoDMY**
S	324^{**}	259^{**}	199^{**}	127^{**}
T	151^{*}	116^{*}	102^{**}	93^{**}
S×T	293^{**}	144^{**}	137^{**}	120^{**}

*=Significant at 0.05 level, **=Significant at 0.01 level

SOV= Source of variance, S= Sowing time, T= Planting geometry, SD= Stem density, PP= Plant population at harvest, PH=Plant height, SDi=Stem diameter, NL=Number of, LA=Leaf area, FW=Fresh weight, DW=Dry weight, SGFY=Sorghum green forage yield, SDMY=Sorghum dry matter yield, SoGFY= Soybean green forage yield, SoDMY=Soybean dry matter yield.

Seedling density and plant population at harvest: An appropriate crop stand is required to use soil as well as environmental resources efficiently and economically as a poor crop stand cannot make efficient use of applied resources such as fertilizers and irrigations. Thus in cereals-legumes intercropping systems, it is necessary to maintain and monitor the seedling density of main crop in order to achieve the added advantage of legumes intercropping. The significantly higher seedling density (p<0.05) of 66.7 and 70.4 m^2 during 2013 and 2014 respectively and plant population of forage sorghum (64.6 and 67.0 m^2 during 2013 and 2014 respectively) were recorded in plots where forage sorghum was sown 18 days earlier to soybean in 2:1 row proportions (S_2T_3) as shown in Fig 2. It was followed by plots where forage sorghum was simultaneously sown with soybean in 2:1 row proportions (S_1T_3). The lowest seedling density and plant population at harvest were recorded when forage sorghum was sown 18 days after soybean in 2:2 row proportions (S_3T_4) (Fig. 2). Sorghum sown 18 days prior to soybean provided more favorable environment for germination of sorghum and resultantly higher seedling density was counted (Carruthers *et al*., 2000). Similarly, plant population at harvest is somehow linked with seedling density and plays an important role in determining the green forage yield. The significantly higher plant population at harvest of forage sorghum in plots where sorghum was sown 18 days earlier to soybean showed that more favorable growth conditions were available which resulted in higher plant population of forage sorghum, while sorghum-soybean sowing at the same time resulted in decreased plant population of forage sorghum at harvest as some of the plants were put out of competition (Marchiol *et al*., 1992; Fortin *et al*., 2013).

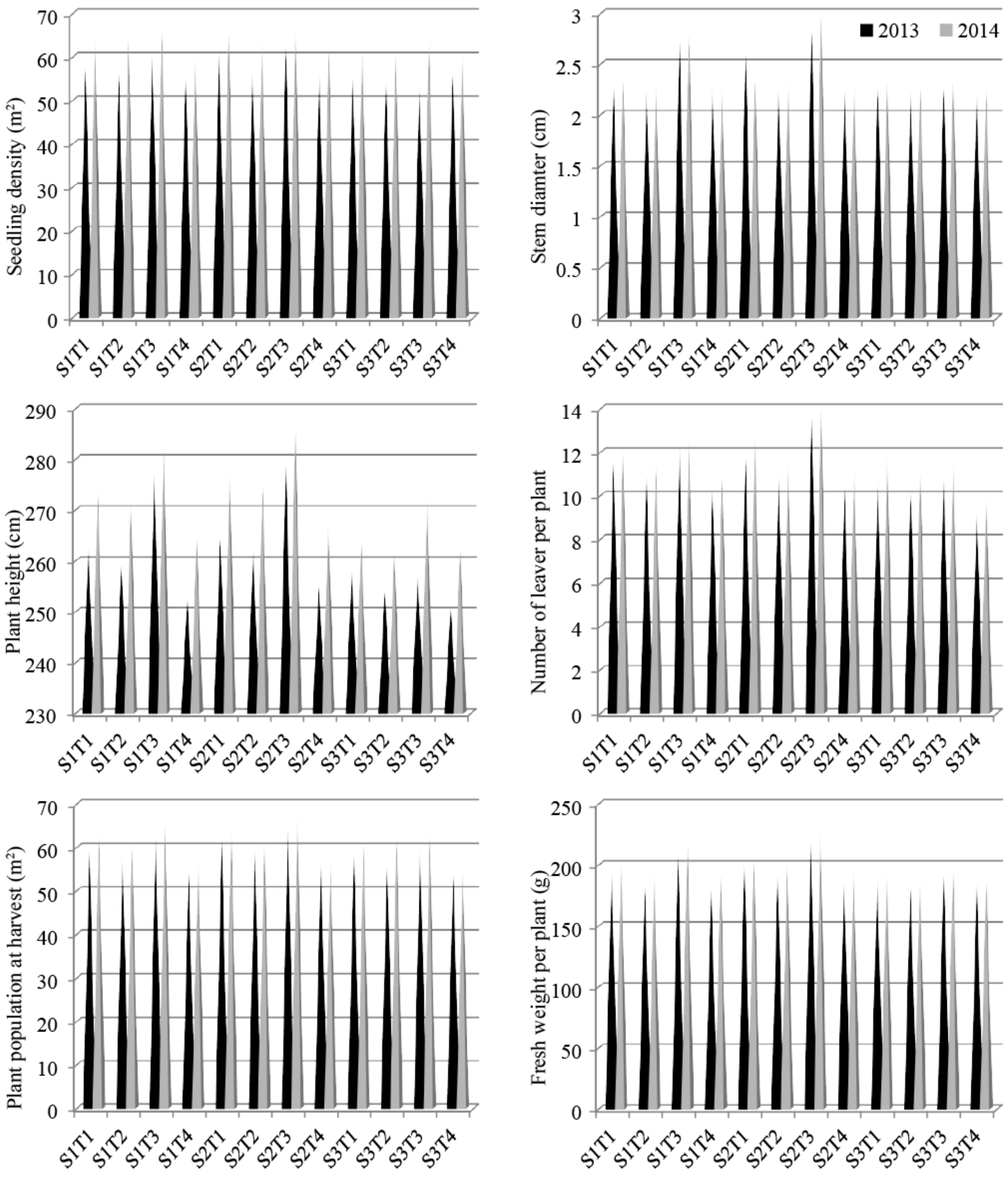

Fig. 2. Agronomic parameters of forage sorghum as affected by planting times and spatial arrangements.

Plant height and stem diameter: Plant height contributes a lion's share towards green forage yield and may be used to estimate the rate of plant growth and development. The interactive effect of both factors was significant as far as plant height (p<0.01) and stem diameter (p<0.05) of sorghum are concerned (Table 2). The tallest sorghum plants with height of 278.6 cm and 286.13 cm during 2013 and 2014 respectively were given by sorghum sown 18 days prior to soybean in 2:1 row proportions (S_2T_3). The same intercropping system was instrumental in yielding the significantly higher stem diameter (1.32 and 1.38 cm during 2013 and 2014) of forage sorghum. It was followed by sorghum-soybean simultaneous sowing in 2:1 row proportions with stem diameter of 1.31 and 1.37 cm during 2013 and 2014 respectively (S_1T_3) (Fig. 2). This comparatively higher plant height and stem diameter might be owing to better utilization of growth resources and nitrogen saving done by soybean which diverted more soil nitrogen to sorghum and ultimately plant height and stem diameter of sorghum were enhanced (Gare *et al*., 2009; Sawyer *et al*., 2010).

Number of leaves and leaf area per plant: Number of leaves and leaf area per pant are critical agronomic parameters because leaves are the photosynthetic factories which maintain source-sink relationship and ultimately determine green forage yield. Statistical analysis revealed that planting times and spatial arrangements were effective in significantly (p<0.05) influencing the number of leaves and leaf area per plant of sorghum. Deferred sowing of soybean for 18 days and spatial arrangement of 2:1 row proportion (S_2T_3) again proved their superiority by recording the significantly highest number of leaves per plant (13.6 and 13.9 during 2013 and 2014 respectively) leaf area per plant (2240.9 cm^2 and 2261.5 cm^2 during 2013 and 2014 respectively) (Fig. 2). Sorghum sown 18 days after soybean in 2:2 row proportions (S_3T_4) performed poorly in terms of number of leaves and leaf area per plant of forage sorghum during both years. This was might be due higher use efficiency of growth resources like moisture and nutrients which triggered the growth of leaves and ultimately more number of leaves per plant were produced and that too with greater length and width. Cereal-legumes intercropping result in comparatively higher absorption of moisture and nutrients by exploiting different soil horizons and resultantly more number of leaves with higher leaf area of forage sorghum were produced (Kadam & Baig, 2005).

Fresh and dry weights per plant: Fresh and dry weights per plant have direct relationship with green forage yield and dry matter yield. Sorghum with the significantly highest (p<0.01) (Table 2) fresh weight (217.3 g and 226.8 g during 2013 and 2014 respectively) and dry biomass per plant (54.18 g and 57.55 g during 2013 and 2014 respectively) were produced when forage sorghum was sown 18 days prior to soybean in 2:1 row proportion (S_2T_3) (Fig. 3). These significantly higher fresh and dry weights per plant of sorghum were owing to significantly higher stem diameter, taller plant height and more number of leaves per plant with greater leaf area. Furthermore, it has been reported that maize-soybean intercropping resulted in higher fresh and dry weights per plant of forage sorghum by influencing the efficacy of farm-applied growth resources (Prasad & Brook, 2005).

Green and dry matter yields of sorghum: A close monitoring of green forage yield as well as dry matter biomass production of sorghum is of utmost importance owing to being the major contributor to total productivity per unit land area. The delayed sowing of soybean for 18 days in 2:1 row proportion (S_2T_3) remained outstanding as it recorded the highest green forage yield (49.98 and 53.25 t ha^{-1} during 2013 and 2014, respectively) and dry matter biomass (15.09 and 16.08 t ha^{-1} during 2013 and 2014, respectively) of sorghum (Fig. 3). It was followed by sorghum-soybean simultaneous sowing in 2:1 row proportions (S_1T_3), which in turn was statistically at par with sorghum sown 18 days earlier to soybean in 4:1 row proportion. The noticeable higher green forage yield and dry matter yield of sorghum was due to higher growth triggered by greater number of leaves with higher leaf area per plant which was bound to increase the photosynthetic rate and resultantly plants with higher fresh and dry weights were obtained, which in turn increased forage yield and dry matter yield on per hectare basis. Earlier it was concluded that sorghum-legumes intercropping was instrumental in giving higher forage yield as well as dry matter yield owing to higher efficacy of soil and environmental resources use in comparison with their pure stands (Rashid & Himayatullah, 2003).

Green and dry matter yields of soybean: Green forage yield and dry matter yield of soybean intercrop is equally important in obtaining the added advantage of sorghum-soybean intercropping. The highest (p<0.01) green forage yield (13.97 and 14.52 t ha^{-1} during 2013 and 2014, respectively) and dry matter yield (8.15 and 8.91 t ha^{-1} during 2013 and 2014, respectively) of soybean were given by soybean sown 18 days prior to sorghum in 2:1 row proportion (S_3T_3) and it was followed by soybean sown 18 days earlier to sorghum in 4:1 row proportion (S_3T_1) (Fig. 4). Soybean sown 18 days prior to sorghum performed better than soybean sown at the same time with forage sorghum which in turn performed better than soybean sown 18 days after sorghum cultivation. 2:1 row proportion of sorghum-soybean gave the highest green forage yield as well as dry matter yield of soybean and it was followed by sorghum-soybean sown in 4:1 row proportion. Similar results were reported by Biabani *et al*. (2008), who concluded that soybean intercropped with cereals under different spatial arrangements had the potential to give higher green forage yield as well as dry matter yield due to higher water use efficiency and photosynthetic rate triggered by varied botanical characteristics of component crops. But contradictory findings have also been reported where soybean growth and yield were suppressed while in intercropping with cereals because cereals were more competitive in capturing growth resources and soybean was comparatively less shade tolerant particularly at early growth stages (Diebel *et al*., 2000). However, in our study, delayed sowing of sorghum resulted in higher productivity of soybean owing to comparatively lesser competition more conducive growth conditions at early growth stages.

Mixed (sorghum + soybean) green forage and dry matter yields: Mixed green forage yield and dry biomass yield determine the true productivity and profitability of cereal-legumes intercropping systems. The highest mixed green forage yield (64.59 and 67.71 t ha^{-1} during 2013 and 2014, respectively) and mixed dry matter yield (22.64 and 23.03 t ha^{-1} during 2013 and 2014, respectively) were produced by intercropping systems where sorghum was sown earlier and soybean sowing was deferred for 18 days in 2:1 row proportion (S_2T_3), while it was followed by sorghum sown 18 days before soybean in 1:1 row proportion (S_2T_1) (60.08 and 64.09 t ha-1 during 2013 and 2014, respectively) (Fig. 4). It was due to the fact that sorghum and soybean exploit different soil horizons because of different root penetration for moisture and nutrients absorption and ultimately higher mixed forage yield and dry matter yield were obtained. Previously, it has been reported that sorghum-soybean sole cropping gave significantly higher green forage yield due to better utilization of growth resources (Ghosh *et al.*, 2006) as that of our study where different sowing time provided component crops the same level of environment as that of their pure stands.

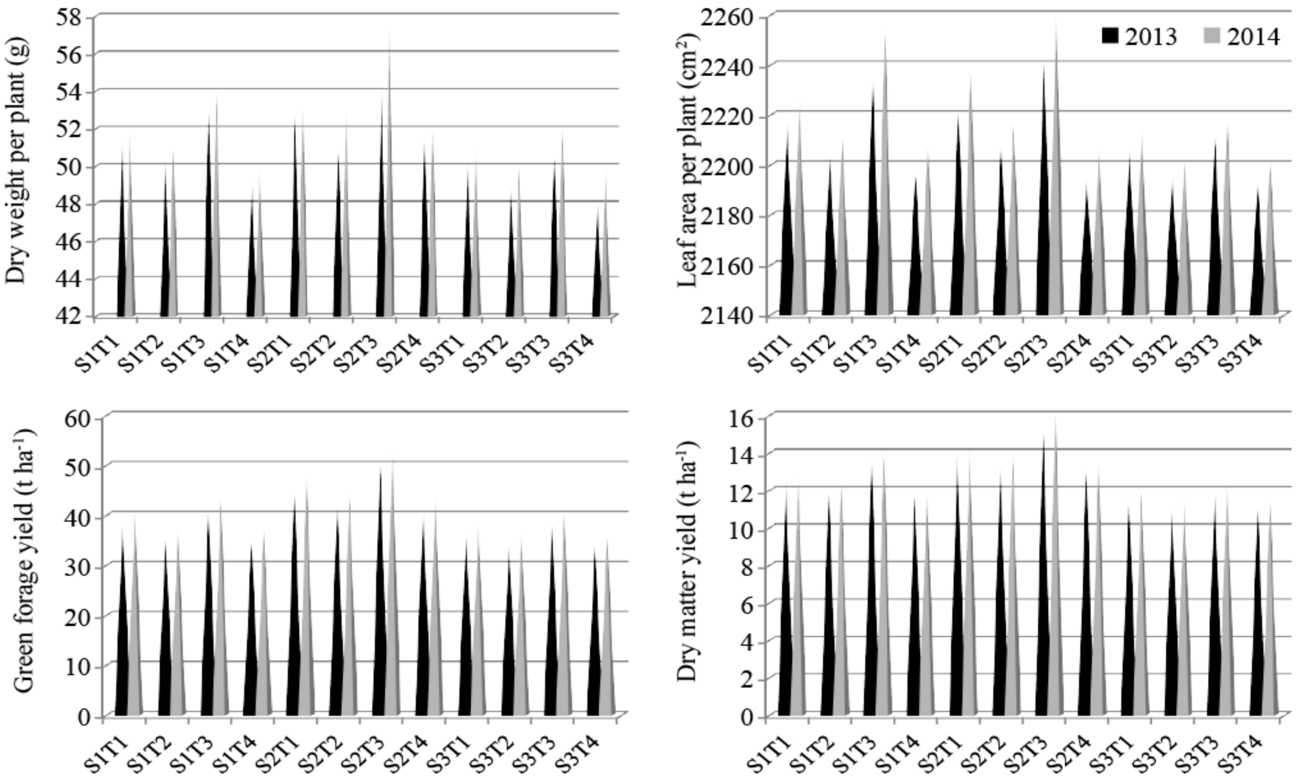

Fig. 3. Fresh and dry weights per plant, green forage yield and dry matter yield of sorghum as affected by planting times and spatial arrangements.

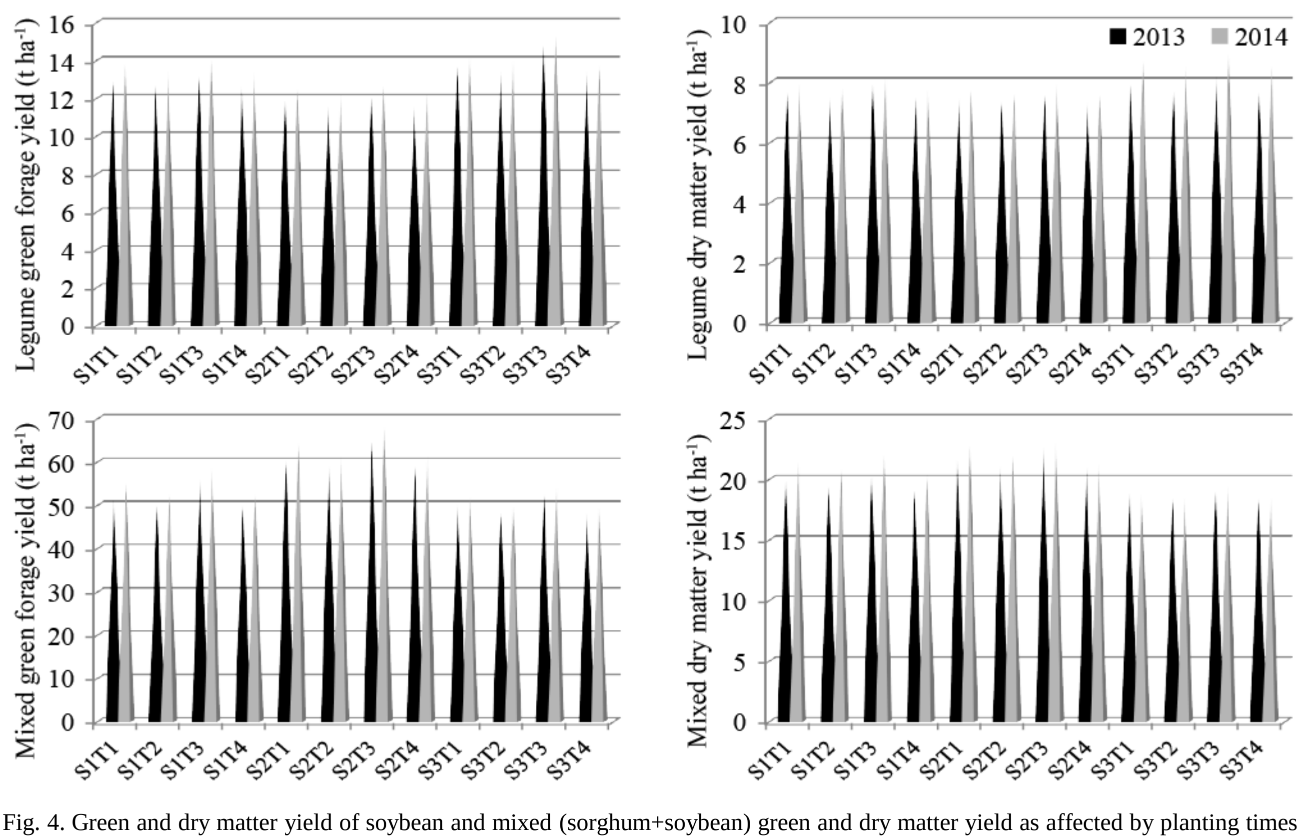

Fig. 4. Green and dry matter yield of soybean and mixed (sorghum+soybean) green and dry matter yield as affected by planting times and spatial arrangements.

S_1T_1= Sorghum and soybean simultaneously sown in 4:1 row proportion S_1T_2= Sorghum and soybean simultaneously sown in 4:4 row proportion S_1T_3= Sorghum and soybean simultaneously sown in 2:1 row proportion S_1T_4= Sorghum and soybean simultaneously sown in 2:2 row proportion S_2T_1= Sorghum sown 18 days prior to soybean in 4:1 row proportion S_2T_2= Sorghum sown 18 days prior to soybean in 4:4 row proportion S_2T_3= Sorghum sown 18 days prior to soybean in 2:1 row proportion S_2T_4= Sorghum sown 18 days prior to soybean in 2:2 row proportion S_3T_1= Soybean sown 18 days prior to sorghum in 4:1 row proportion S_3T_2=Soybean sown 18 days prior to sorghum in 4:4 row proportion S_3T_3= Soybean sown 18 days prior to sorghum in 2:1 row proportion S_3T_4= Soybean sown 18 days prior to sorghum in 2:2 row proportion.

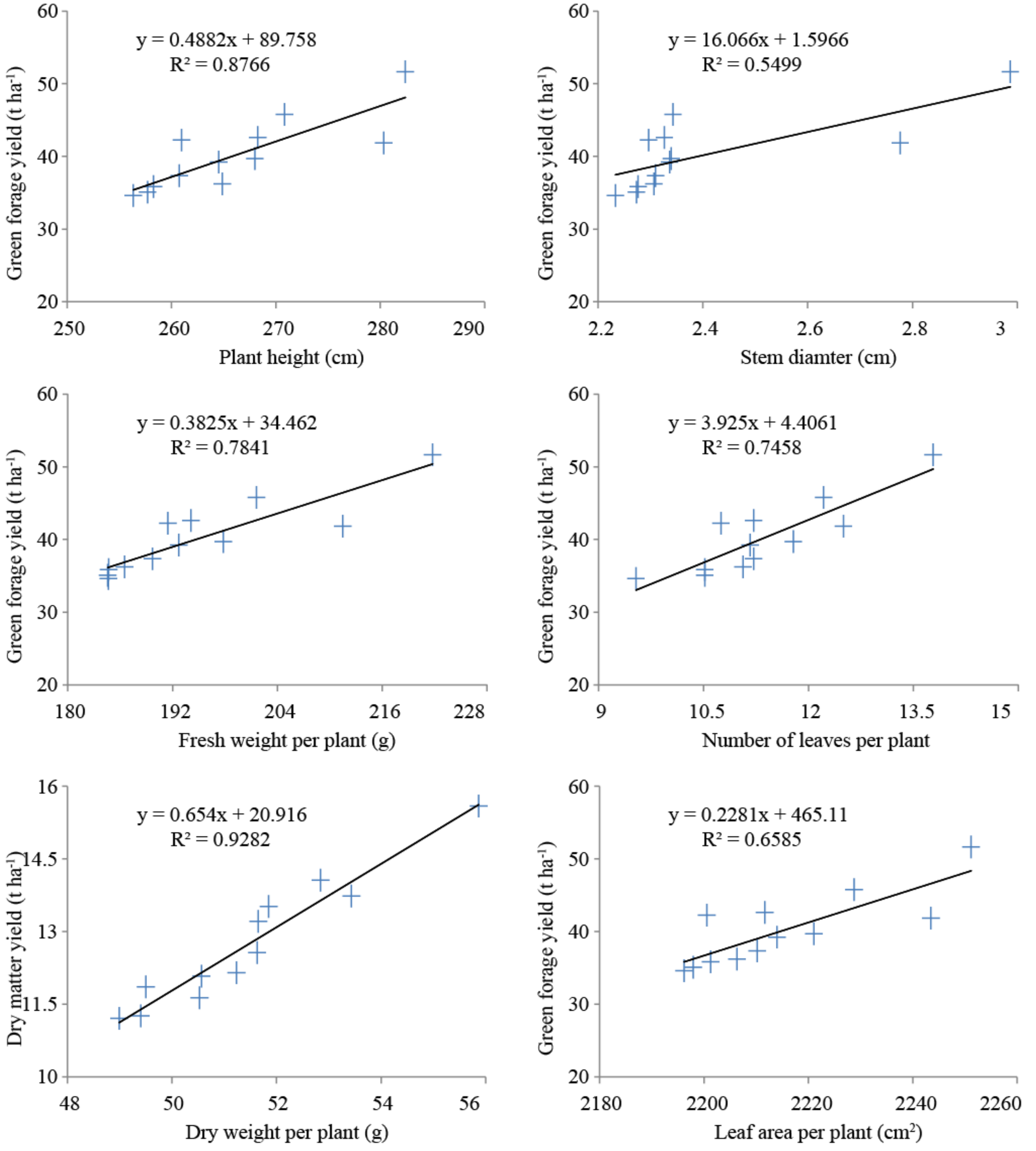

Fig. 5. Correlation of agronomic variables of sorghum with green forage yield and dry matter biomasss (2 years combined analysis).

Conclusions

We investigated the productivity of sorghum-soybean intercropping systems by varying the sowing time of component crops for 18 days along with their simultaneous cultivation under different planting geometries. Our results showed that sorghum-soybean intercropping has the potential to yield significantly higher forage particularly when sorghum was sown 18 days prior to soybean in 2:1 row proportion. 2:1 row proportion of sorghum and soybean was the most suitable spatial arrangement as it enhanced the degree of complimentary use of growth resources in sorghum-soybean intercropping systems. On contrary, forage yield of soybean remained unmatched when sorghum sowing was deferred for 18 days and spatial arrangement of 2:2 row proportions was adopted. However, sorghum sowing prior to soybean for 18 days in 2:1 row proportion was proved to be superior in terms of mixed (sorghum + soybean) green forage yield and dry matter biomass. Thus this intercropping system might be suggested to forage growers after conducting cultivar and site specific field investigations under varied agro-climatic and agro-ecological conditions.

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