Effect of plant density on canopy structure and dry matter partitioning into plant parts of soybean (*Glycin max*)

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Abstract: The genotype with higher dry matter production and its proper distribution resulted in higher seed yield and proper distribution of assimilates into plant parts depends on optimum spacing of a genotype. Therefore, there is need to study dry mass partitioning into plant parts under different plant density to find out optimum plant density for a newly developed variety. The experiment was conducted under sub-tropical condition (24°75´ N latitude and 90°50´ E longitude) to investigate the effect of plant spacing on morphological characters, dry mass production and its partitioning into plant parts, yield attributes and yield of newly developed two soybean varieties. The experiment comprised two types of varieties viz., BINAsoybean-1(large canopy) and BINAsoybean-2 (small canopy) and four plants spacing of 5 cm × 30 cm, 10 cm × 30 cm, 15 cm × 30 cm and 20 cm × 30 cm. The experiment was laid out in two factor randomized complete block design with four replicates. Morpho-physiological characters such as root length, lateral root number, plant height, number of branches and leaves plant^{-1} as well as leaf area plant^{-1}, total dry mass production plant^{-1}, yield attributes such as number of pods and seeds plant^{-1} and seed yield plant^{-1} were increased with increasing plant spacing while reverse trend was observed in plant height and seed yield m^{-2}. The genotype having lower canopy area requires narrows plant spacing and vice versa. The larger canopy bearing genotype, BINAsoybean-1 performed best at the moderate spacing of 10 cm × 30 cm and the lower canopy bearing genotype, BINAsoybean-2 performed well at the closer spacing of 5 cm × 30 cm. Plant density had no significant influence on proportion of dry matter partitioning into different plant parts.

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1. Introduction

Soybean (*Glycin max* (L.) Merr.) is one of the most important oil seed legume crops of the world. It is considered as an important economic food legume cultivated worldwide because of its higher nutritional and industrial values. Soybean is a good source of protein, unsaturated fatty acids, minerals like Ca and P including vitamin A, vitamin B, vitamin C and vitamin D which can meet-up different nutritional needs of human and animals (Mondal et al., 2012a).

Planting density is one of the main factors that has an important role on growth and yield of soybean. Optimum plant density ensures proper growth of the aerial and underground parts of the plant through efficient utilization of solar radiation, nutrients, land as well as air spaces and water (Malek et al., 2012). There are two general concepts to describe the relationship between plant density and seed yield. Firstly, irrespective of plant spacing within and among rows, plant density must be such that the crop develops a canopy able to intercept more than 95% of the incoming solar radiation during reproductive growth and secondly, a nearly equidistant plant arrangement minimizes interplant competition and produces maximum seed yield. Kang et al. (2001) reported that appropriate plant density and cultivar is necessary for obtaining high yield and quality of soybean. The optimum plant density for higher yield may differ from cultivar to cultivar and location to location. Research report on effect of plant density on newly developed two soybean varieties viz. BINAsoybean-1 and BINAsoybean-2 (registered as variety in 2012) to seed yield is scarce in Bangladesh.

On the other hand, the productivity of soybean can be increased by selecting suitable variety. The varieties with higher dry matter production and its proper distribution resulted in higher seed yield. Roots and shoots together constitute the entire plant structure. These two plant parts are competing for water, nutrients and metabolic products. The optimum proportion of dry mass between these parts should be partitioned if the final yield is to be maximized (Gorney & Larson, 1989). However, the relation between stem size and root size trends to be changeable under different plant density. A large root system consume reserves and assimilates from a large area which could be used for yield formation while a smaller one limits the absorption of water and minerals and hence photosynthesis. Several researchers reported that the genotypes which produced greater TDM also showed higher yield due to large root system and leaf area (Manral & Saxena, 2005; Mondal et al., 2012b; Markos et al., 2002).

However, dry mass partitioning into reproductive organ is largely determined by the degree of competition for assimilates between vegetative and reproductive sink and this competition influenced by planting density (Malek et al., 2012). Therefore, there is need to study dry mass partitioning into plant parts under different plant density. Literature on root and shoot growth of soybean, dry matter partitioning and their inter-relationships under different plant densities are few and scanty. This study was undertaken to find out optimum plant density for maximizing seed yield through dry matter production ability and their patterns of distribution to different plant parts in soybean.

2. Materials and Methods

The experiment was conducted at the experimental field of Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh during the period from December 2012 to April 2013. Two recently released mungbean varieties (released in 2012) namely BINAsoybean-1 and BINAsoybean-2 were used in the experiment. Seeds were sown in line distance between two lines was 30 cm and within row, plant to plant distance was 5, 10, 15 and 20 cm. Here we considered planting distance range from 5 cm to 20 cm because of the national recommended plant to plant distance of released varieties was 10 cm (BARI, 2008). The experiment was laid out in two factor randomized complete block design with four replicates. The unit plot size was 2.5 cm × 2.5 m. The soil characteristic of the experimental field was sandy loam having soil pH 6.8. The land was prepared properly with ploughing and laddering. The fertilizers were applied during the final land preparation at the rate of 40, 80 and 60 kg ha^{-1} of urea, triple superphosphate and muriate of potash, respectively. The seeds were firstly mixed with molasses for adhering to the biofertilizer. After that biofertilizer was mixed thoroughly with the seeds and the seeds were placed in a cool and dry place to avoid sticking together. Seeds were then sown on December 05, 2012 at about 3-4 cm depth from the soil surface apart from 5, 10, 15 and 20 cm plant to plant distance depending on the treatment. Different intercultural operations such as weeding, thinning, irrigation and pesticide spray were done as and when necessary. For dry matter partitioning study, two harvests were made at R2 (55 DAS) and R7 (115 DAS) reproductive stages. The second row of each plot was used for sampling. From each sampling, 10 competitive plants were randomly selected from each plot and uprooted for collecting necessary parameters. The plants were separated into roots, stems, leaves and pods, and the corresponding dry weight were recorded after oven drying at 80 ± 2 ^{0}C for 72 hours. The leaf area of each sample was measured by automatic leaf area meter (Model: LICOR 3000, USA) at R6 reproductive growth stage, before starting leaf shedding. The yield contributing characters were recorded at harvest from ten competitive plants of each plot. The seed yield was recorded from five rows of each plot (1.50 m × 2.5 m) and converted into seed weight $hectare^{-1}$. Harvest index was determined as: (Grain yield $plot^{-1}$ ÷ biological yield $plot^{-1}$) × 100. Data were analyzed statistically as per the design used following the analysis of variance (ANOVA) technique and the mean differences were adjusted with DMRT at 5% level of significance using the statistical computer package programme, MSTAT-C following Russell (1986).

3. Results

3.1 Canopy structure

***3.1.1 Effect of plant density*:** The plant density had significant influence on root length, number of lateral roots $plant^{-1}$, plant height, number of branches, pod bearing nodes and leaves $plant^{-1}$ and leaf area (LA) $plant^{-1}$ (Table 1). Results indicated that the above studied parameters gradually increased with increasing plant spacing except plant height. The plant height decreased gradually with increasing plant spacing. The highest root length (14.65 cm), number of lateral roots $plant^{-1}$ (20.0), number of branches (3.7), pod bearing nodes (11.38) and leaves (17.20) $plant^{-1}$ and leaf area $plant^{-1}$ (629 cm^2) was observed at the wider spacing of 20 cm × 30 cm followed by spacing of 15 cm × 30 cm with same statistical rank (Table 1). In contrast, the lowest above parameters was recorded in the plant spacing of 5 cm × 30 cm.

3.1.2 Effect of variety: Variety had significant influence on all canopy structure related parameters except number of lateral roots $plant^{-1}$ (Table 1). Between the varieties, BINAsoybean-1 had greater root length, number of lateral roots, pod bearing nodes and leaves $plant^{-1}$, plant height and leaf area $plant^{-1}$ than BINAsoybean-2 while branch number was higher in BINAsoybean-2 than BINAsoybean-1.

***3.1.3 Interaction effect of variety and spacing*:** The interaction effect of variety and plant spacing on canopy structure related parameters was significant (Table 2). Results revealed that the morphological characters such as root length, number of lateral roots, branches, pod bearing nodes and leaves $plant^{-1}$ and LA $plant^{-1}$ increased with increasing plant spacing while reverse trend was observed in case of plant height in both the varieties. However, the influence of planting density on the above parameters was greater in BINAsoybean-1 (large canopy) than BINAsoybean-2 (small canopy). For example, plant height decreased

13.7% in wider spacing (20 cm × 30 cm) over closer spacing (20 cm × 30 cm) in BINAsoybean-1 whereas plant height decreased only 6.9% in BINAsoybean-2.

3.2 Dry matter partitioning

3.2.1 Effect of plant density**:** The effect of plant spacing on dry mass production and distribution both at flowering stage and at harvest was significant (Tables 3 & 5). Results showed that total dry mass plant^{-1} increased gradually with increasing plant spacing at both the growth stages. However, dry mass allocation into root, stem, leaf, husk and seed weight plant^{-1} was almost constant at any plant spacing. These results indicate that plant spacing influence dry matter production but not allocation among the different plant parts in soybean. The harvest index (HI) was not greatly influenced by plant spacing (Table 5). The highest harvest index (34.59%) was recorded in 10 cm × 30 cm plant spacing followed by plant spacing of 15 cm × 30 cm (33.16%) with same statistical rank indicating dry matter partitioning to economic yield is well in moderate plant spacing.

3.2.2 Effect of variety: The total dry mass production and distribution in plant parts were significantly greater in BINAsoybean-1 than in BINAsoybean-2 (Tables 3 & 5). Total DM production is determined by magnitude of DM partitioning into root and shoot growth. At flowering stage, in BINAsoybean-1, thus increased DM partitioning into root and shoot growth resulted greater TDM production than in BINAsoybean-2. Among the different plant parts, leaf weight contributed the highest (average 52.3%) of total dry mass production followed by stem weight (average 29.9%) (Table 3). At harvest, among the different plant parts, seed weight contributed the highest (average 33.1%) of total dry mass production followed by stem weight (average 29.9%). In contrast, root contributed the lowest (average 9.64%) of the TDM. This result indicates that leaf weight is more important for getting higher seed yield because of seed yield is strongly depend on leaf area as well as leaf weight.

3.2.3 Interaction effect of variety and spacing**:** Results showed that TDM production increased with increasing plant spacing in both the varieties but increment was not similar between the varieties (Tables 4 & 6). The increased in TDM due to increasing plant spacing was greater in BINAsoybean-1 than in BINAsoybean-2 at both growth stages. However, dry matter partitioning into different plant parts was similar in both the varieties at any plant spacing. This result indicates that dry matter partitioning into plant parts does not influence by plant spacing in any genotype.

3.3 Yield components

3.3.1 Effect of plant density**:** The yield attributes and seed yield significantly influenced by plant spacing except 100-seed weight (Table-7). Results revealed that number of pods and seeds plant^{-1} as well as seed yield plant^{-1} increased with increasing plant spacing in soybean. The highest number of pods and seeds plant^{-1} was observed in wider spacing of 20 cm × 30 cm resulted the highest seed weight plant^{-1} (10.4 g) followed by plant spacing of 15 cm × 30 cm (10.0 g) with same statistical rank. The lowest seed yield plant^{-1} (5.04 g) was recorded in closer spacing of 5 cm × 30 cm due to inferior performance in yield contributing characters. However, based on unit area, the seed yield decreased with increasing plant spacing. The highest seed yield was recorded at the closer spacing of 5 cm × 30 cm (278 g m^{-2}) followed by the spacing of 10 cm × 30 cm (249 g m^{-2}). The lowest seed yield was recorded in wider spacing of 20 cm × 30 cm (166 g m^{-2}).

3.3.2 Effect of variety: The higher seed yield was observed in BINAsoybean-2 than BINAsoybean-1 due to increased number of seeds plant^{-1} although number of pods plant^{-1} was similar and seed size was less than BINAsoybean-1.

3.3.3 Interaction effect of variety and spacing**:** The interaction effect of variety and plant spacing on yield components and seed yield was significant except 100-seed weight (Table 8). Results revealed that the yield components such as number of pods and seeds plant^{-1}, number of seeds pod^{-1} and seed weight plant^{-1} increased with increasing plant spacing in both the varieties but the increment was not similar in both the varieties. However, the influence of plant spacing on yield components was greater in BINAsoybean-1 (large canopy) than BINAsoybean-2 (small canopy). For example, number of pods plant^{-1} increased 111% in wider spacing (20 cm × 30 cm) over closer spacing (5 cm × 30 cm) in BINAsoybean-1 whereas the number of pods plant^{-1} increased only 44.2% in BINAsoybean-2. Again, the prime yield attributes number of pods and seeds plant^{-1} of BINAsoybean-1 increased with increasing plant spacing whereas these two parameters increased till plant spacing of 15 cm × 30 cm followed by no significant increased in BINAsoybean-2. These results indicate that optimum plant spacing in soybean varieties depends on canopy size. Considering unit area basis on seed yield, results showed that seed yields were higher in two plant spacings of 5 cm × 30 cm and 10 cm × 30 cm than the other two wider spacings of 15 cm × 30 cm and 20 cm × 30 cm in BINAsoybean-1. On the other hand, the seed yield m^{-2} decreased significantly with increasing plant spacing and the highest seed yield was observed in closer spacing of 5 cm × 30 cm in BINAsoybean-2. Therefore, BINAsoybean-1 requires moderate plant spacing of 10 cm × 30 cm for its larger canopy size and BINAsoybean-2 requires closer plant spacing of 5 cm × 30 cm for its shorter canopy structure. However, the dry matter partitioning to economic yield was also improved at above optimum plant spacing of the varieties (Table 6).

4. Discussion

Most of the morphological characters, yield attributes and seed and biological yields of soybean were tremendously influenced by plant spacing. Taller plant in closer spacing might have resulted due to competition for sunlight than those of wider spacing because of densely population in closer spacing. This result is in agreement with Malek et al. (2012) who reported that plant height increased with decreasing plant spacing. Reduction in branch number plant^{-1}, LA plant^{-1} and TDM plant^{-1} in closer spacing might be due to increased number of plants unit^{-1} area and their inter competition. On the other hand, many workers reported that plant morphological characters increased with increasing plant spacing except plant height (Babalal et al., 2005; Mondal et al., 2012c, Malek et al., 2012). In the present experiment, plant morphological characters increased with increasing plant spacing that supported earlier results. However, the proportion of dry mass allocation into root, stem, leaf, husk and seed weight plant^{-1} was almost constant at any plant spacing. These results indicate that plant spacing influence dry matter production but not allocation among the different plant parts in soybean. This result is agrees with Egli (1988). Further, variation in morphological characters such as plant height, number of branches and leaves plant^{-1} and LA between the varieties is mostly due to the differences in their genetic makeup (Mondal et al., 2011).

HI is a measure of the efficiency of conversion of photosynthate into economic yield of a crop plant (Dutta & Mondal, 1998). According to Poehlman (1991), high yield is determined by physiological process leading to a high net accumulation of photosynthates and it's partitioning into plant and seed. This opinion has been reflected in the moderate plant spacing. In the present investigation, high yield giving spacing maintained high HI.

Table 1. Effect of planting density and variety on canopy structure in soybean

Treatment	Root length (cm)	Lateral roots plant^{-1} (no)	Plant height (cm)	Branches plant^{-1} (no)	Pod bearing nodes plant^{-1} (no.)	Leaves plant^{-1} (no)	Leaf area plant^{-1} (cm^2) at R_6 stage
Plant spacing							
5 cm × 30 cm	11.30 c	13.72 b	53.44 a	2.34 d	9.37 b	11.57 b	425 c
10 cm × 30 cm	13.18 b	15.31 b	49.90 b	2.80 c	9.79 b	13.26 b	461 c
15 cm × 30 cm	14.51 a	18.79 a	48.71 b	3.23 b	11.4 a	15.70 a	584 b
20 cm × 30 cm	14.65 a	20.00 a	47.49 b	3.70 a	11.4 a	17.20 a	629 a
F-test	**	**	**	**	**	**	**
Variety							
BINAsoybean-1	14.11 a	17.01	61.50 a	2.76 b	11.34 a	16.34 a	611 a
BINAsoybean-2	12.70 b	16.90	38.26 b	3.28 a	9.62 b	12.52 b	439 b
F-test	*	NS	* *	**	**	**	**
CV (%)	8.68	11.0	4.67	9.92	5.92	10.96	6.64

In a column, figures having the same letter (s) do not differ significantly as per DMRT at $P \leq 0.05$; **, Significant at 1% level of probability

Table 2. Interaction effect of variety and planting density on canopy structure in soybean

Interaction		Root length (cm)	Lateral roots plant^{-1} (no)	Plant height (cm)	Branches plant^{-1} (no)	Pod bearing nodes plant^{-1} (no)	Leaves plant^{-1} (no)	Leaf area plant^{-1} (cm^2) at R_6 stage
Variety	*Spacing*							
V_1	5 cm × 30 cm	11.81cd	13.36 c	66.66 a	2.13 d	9.90 bc	13.80b	480 b
	10 cm × 30 cm	13.70ab	15.61bc	61.70 b	2.50 cd	10.32 b	14.66 b	512 b
	15 cm × 30 cm	15.50 a	18.77ab	60.11 b	3.00 bc	12.60 a	17.40 a	696 a
	20 cm × 30 cm	15.46 a	20.30 a	57.53 b	3.40 b	12.56 a	19.50 a	756 a
V_2	5 cm × 30 cm	10.79 d	14.08 c	40.22 c	2.55 cd	8.83 c	9.33 d	370 c
	10 cm × 30 cm	12.66bc	15.00 c	38.10 c	3.10 b	9.26 bc	11.87 c	410 c
	15 cm × 30 cm	13.51bc	18.81ab	37.30 c	3.46 b	10.20 b	14.00b	472 b
	20 cm × 30 cm	13.85ab	19.70 a	37.45 c	4.00 a	10.20 b	14.90 b	502 b
F-test		*	*	*	*	**	*	**
CV (%)		8.68	11.0	4.67	9.92	5.92	10.96	6.64

In a column, figures having the same letter (s) do not differ significantly as per DMRT at $P \leq 0.05$; * & **, significant at 5% and 1% level of probability, respectively; V_1, BINAsoybean-1; V_2, BINAsoybean-2

Table 3. Effect of planting density and variety on dry matter production and partitioning into plant parts in soybean at R_2 reproductive growth stage

Treatment	Component wise dry matter production (in gram) and partitioning (in %) per plant				
	Root weight	Stem weight	Leaf weight	Peduncle weight	Total dry mass
Plant spacing					
5 cm × 30 cm	0.97 c *(14.7)*	2.01 b *(30.5)*	3.44 d *(52.3)*	0.16 c *(2.43)*	6.58 d
10 cm × 30 cm	1.22 b *(16.2)*	2.26 b *(29.9)*	3.88 c *(51.4)*	0.19 b *(2.52)*	7.55 c
15 cm × 30 cm	1.44 a *(15.7)*	2.72 a *(29.6)*	4.82 b *(52.4)*	0.21 ab *(2.29)*	9.19 b
20 cm × 30 cm	1.46 a *(14.8)*	2.93 a *(29.7)*	5.24 a *(53.1)*	0.23 a *(2.33)*	9.86 a
F-test	**	**	**	**	**
Variety					
BINAsoybean-1	1.22	2.64 a	4.84 a	0.18 b	8.87 a
BINAsoybean-2	1.33	2.32 b	3.85 b	0.21 a	7.78 b
F-test	NS	**	**	**	**
CV (%)	10.54	9.30	6.41	7.17	5.85

In a column, figures having the same letter (s) do not differ significantly as per DMRT at P ≤ 0.05; **, significant at 1% level of probability; Figures in parenthesis indicate percent contribution of total dry matter production.

Table 4. Interaction between variety and planting density on dry matter production and partitioning into plant parts in soybean at R_2 reproductive growth stage

Interaction		Component wise dry matter production (in gram) and partitioning (in %) per plant				
		Root weight	Stem weight	Leaf weight	Peduncle weight	Total dry mass
Variety	*Spacing*					
V_1	5 cm × 30 cm	0.88 b *(12.9)*	2.14 de *(31.3)*	3.68 d *(53.8)*	0.14 d *(2.05)*	6.84 e
	10 cm × 30 cm	1.08 b *(13.5)*	2.37 cd *(29.6)*	4.40 c *(54.9)*	0.16 cd *(2.00)*	8.01 d
	15 cm × 30 cm	1.38 a *(14.0)*	2.88 ab *(29.3)*	5.37 b *(54.6)*	0.20 b (2.03)	9.83 b
	20 cm × 30 cm	1.52 a *(14.1)*	3.18 a *(29.4)*	5.90 a *(54.6)*	0.21ab *(1.94)*	10.8 a
V_2	5 cm × 30 cm	1.05 b *(16.7)*	1.88 e *(29.8)*	3.19 d *(50.6)*	0.18 bc *(2.86)*	6.30 e
	10 cm × 30 cm	1.35 a *(19.1)*	2.15 de *(30.4)*	3.36 d *(47.5)*	0.21 ab *(2.97)*	7.07 e
	15 cm × 30 cm	1.50 a *(17.6)*	2.55 bc *(29.9)*	4.26 c *(50.0)*	0.22 ab *(2.56)*	8.52 cd
	20 cm × 30 cm	1.54 a *(17.0)*	2.68 bc *(29.6)*	4.58 c *(50.7)*	0.24 a *(2.65)*	9.04 bc
F-test		*	*	*	*	*
CV (%)		10.54	9.30	6.41	7.17	5.85

In a column, figures having the same letter (s) do not differ significantly as per DMRT at P ≤ 0.05; *, significant at 5% level of probability; V_1, BINAsoybean-1; V_2, BINAsoybean-2; Figures in parenthesis indicate percent contribution of total dry matter production

Table 5. Effect of planting density and variety on dry matter production and partitioning into plant parts in soybean at maturity stage

Treatment	Component wise dry matter production (in gram) and partitioning (in %) per plant						
	Root weight	Stem weight	Leaf weight	Husk weight	Seed weight	Total dry mass	Harvest index (%)
Plant spacing							
5 cm × 30 cm	1.59 c *(11.2)*	4.31 d *(30.4)*	2.04 c *(14.4)*	1.74 c *(12.3)*	4.49 c *(31.7)*	14.17 c	31.43 b
10 cm × 30 cm	1.94 b *(9.96)*	5.63 c *(28.9)*	2.47 b *(12.7)*	2.70 b *(13.9)*	6.74 b *(34.6)*	19.47 b	34.59 a
15 cm × 30 cm	2.24 a *(8.83)*	7.55 b *(29.8)*	3.72 a *(14.7)*	3.42 a *(13.5)*	8.44 a *(33.3)*	25.37 a	33.16 a
20 cm × 30 cm	2.25 a *(8.59)*	7.96 a *(30.4)*	3.93 a *(15.0)*	3.47 a *(13.2)*	8.58 a *(32.8)*	26.19 a	32.79 ab
F-test	**	**	**	**	**	**	*
Variety							
BINAsoybean-1	2.13 a	6.38	3.16 a	2.78	6.95	21.41	32.04
BINAsoybean-2	1.88 b	6.35	2.93 b	2.88	7.17	21.23	33.94
F-test	**	NS	**	NS	NS	NS	NS
CV (%)	10.35	5.25	7.51	7.50	6.52	9.02	7.10

In a column, figures having the same letter (s) do not differ significantly as per DMRT at $P \leq 0.05$; * & **, significant at 5% and 1% level of probability, respectively; NS, not significant; Figures in parenthesis indicate percent contribution of total dry matter production.

Table 6. Interaction effect of variety and planting density and variety on dry matter production and partitioning into plant parts in soybean at maturity stage

Treatment		Component wise dry matter production (in gram) and partitioning (in %) per plant						
		Root weight	Stem weight	Leaf weight	Husk weight	Seed weight	Total dry mass	Harvest index (%)
Variety	*Spacing*							
V_1	5 cm × 30 cm	1.68 d *(13.1)*	4.01e *(31.3)*	2.00 f *(15.6)*	1.46 d *(11.4)*	3.66 f *(28.6)*	12.81 d	28.57
	10 cm × 30 cm	2.09 bc *(11.3)*	5.16 d *(27.8)*	2.52 d *(13.6)*	2.51 b *(13.5)*	6.28 d *(33.8)*	18.56bc	33.84
	15 cm × 30 cm	2.30 ab *(8.70)*	7.69 b *(29.1)*	3.93 ab *(14.9)*	3.54 a *(13.4)*	8.87 a *(33.5)*	26.43 a	33.45
	20 cm × 30 cm	2.44 a *(8.76)*	8.64 a *(31.0)*	4.18 a *(15.0)*	3.60 a *(12.9)*	9.00 a *(32.3)*	27.86 a	32.31
V_2	5 cm × 30 cm	1.49 d *(9.54)*	4.61 d *(29.5)*	2.09 ef *(13.4)*	2.02 c *(12.9)*	5.31 e *(34.0)*	15.62cd	34.29
	10 cm × 30 cm	1.78 cd *(8.73)*	6.10 c *(29.9)*	2.42 de *(11.9)*	2.88 b *(14.1)*	7.20 c *(35.3)*	20.38 b	35.33
	15 cm × 30 cm	2.18 ab *(8.93)*	7.40 b *(30.3)*	3.51 c *(14.4)*	3.29 a *(13.5)*	8.02 b *(32.9)*	24.40 a	32.87
	20 cm × 30 cm	2.06 bc *(8.40)*	7.28 b *(29.7)*	3.68 bc *(15.0)*	3.34 a *(13.6)*	8.16 ab *(33.3)*	24.52 a	33.27
F-test		*	**	**	**	**	**	NS
CV (%)		10.35	5.25	7.51	7.50	6.52	9.02	7.10

In a column, figures having the same letter (s) do not differ significantly as per DMRT at $P \leq 0.05$; V_1, BINAsoybean-1;
V_2, BINAsoybean-2; * &**, significant at 5% and 1% level of probability, respectively; NS, not significant; Figures in parenthesis indicate percent contribution of total dry matter production

Table 7. Effect of planting density and variety on yield components and yield in soybean

Treatment	Pods plant^{-1} (no)	Seeds pod^{-1} (no)	Seeds plant^{-1} (no)	100-seed weight (g)	Seed weight plant^{-1} (g)	Seed yield (g m^{-2})
Plant spacing						
5 cm × 30 cm	22.12 c	1.96 b	43.05 c	13.21	5.04 c	278 a
10 cm × 30 cm	31.80 b	2.25 a	70.11 b	13.23	8.04 b	249 b
15 cm × 30 cm	37.42 a	2.42 a	87.82 a	13.38	10.0 a	206 c
20 cm × 30 cm	38.01 a	2.41 a	90.62 a	13.32	10.4 a	166 d
F-test	**	**	**	NS	**	**
Variety						
BINAsoybean-1	32.22	2.08 b	67.60 b	14.03 a	8.32	215 b
BINAsoybean-2	32.45	2.44 a	78.20 a	12.54 b	8.42	234 a
F-test	NS	**	**	**	NS	*
CV (%)	6.61	6.51	6.11	3.74	6.99	9.31

In a column, figures having the same letter (s) do not differ significantly as per DMRT at $P \leq 0.05$; * & **, significant at 5% and 1% level of probability, respectively; NS, not significant

Table 8. Interaction effect of variety and planting density on yield components and yield in soybean

Interaction		Pods plant^{-1} (no)	Seeds pod^{-1} (no)	Seeds plant^{-1} (no)	100-seed weight (g)	Seed weight plant^{-1} (g)	Seed yield (g m^{-2})
Variety	*Spacing*						
V_1	5 cm × 30 cm	19.13 f	1.73 d	33.10 d	13.98	4.16 e	230 c
	10 cm × 30 cm	30.80 d	2.00 c	60.60 c	13.92	7.59 c	237 c
	15 cm × 30 cm	38.63 ab	2.30 ab	86.15 ab	14.15	10.5 ab	222 cd
	20 cm × 30 cm	40.33 a	2.27 abc	90.55 a	14.08	11.1 a	177 e
V_2	5 cm × 30 cm	25.11 e	2.19 bc	53.00 c	12.44	5.91 d	325 a
	10 cm × 30 cm	32.80 cd	2.49 a	79.63 b	12.54	8.49 c	267 b
	15 cm × 30 cm	36.20 bc	2.53 a	89.48 a	12.60	9.52 b	190 de
	20 cm × 30 cm	35.70 bc	2.55 a	90.69 a	12.57	9.76 b	154 e
F-test		**	*	**	NS	**	**
CV (%)		6.61	6.51	6.11	3.74	6.99	9.31

In a column, figures having the same letter (s) do not differ significantly as per DMRT at $P \leq 0.05$; V_1, BINAsoybean-1;
V_2, BINAsoybean-2; * & **, significant at 5% and 1% level of probability, respectively; NS, not significant

Number of pods plant^{-1} increased with increasing spacing might be due to fact that have fewer number of plants unit^{-1} area which allowed more nutrients and space for growth and development thereby producing more branches and LA that has capacity to produce more photo-assimilates and TDM and resulted higher number of pods plant^{-1} (Malek et al., 2012). On the other hand, fewer numbers of pods plant^{-1} in closer spacing might be due to lesser amount of assimilate production by the plants through lesser photosynthetic area plant^{-1} (Table 1) and competition of nutrients uptake by the plants. Although number of pods plant^{-1} was the lowest in closer spacing but seed yield m^{-2} was the highest due to increase plant accommodation in closer spacing than that of wider spacing. Similar result was partially reported by many workers in soybean (Ball et al., 2000; Gratero & Montilla, 2003; Babalal et al., 2005; Acko & Tradan, 2008). The authors observed that seed yield increased with increasing plant spacing to certain levels and thereafter decreased.

5. Conclusion

Plant spacing had significant influence on total dry matter production but not dry matter partitioning into different plant parts. In other words, dry matter partitioning into plant parts is constant under any plant spacing. Results indicated that optimum plant spacing in soybean depend on canopy area of a genotype. The optimum plant spacing of BINAsoybean-1, the large canopy structure genotype, was 10 cm × 30 cm and 5 cm × 30 cm for BINAsoybean-2, the small canopy structure genotype. Further experimentation is needed for confirmation of the results.

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