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Study the Influence of crop geometry on growth of soybean (Glycine max L. Merrill)

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Abstract
A field experiment was conducted during *Kharif* 2024 at the Experimental Farm, Department of Agronomy, VNMKV, Parbhani to study the Influence of crop geometry on growth and yield of soybean (Glycine max L. Merrill)". The experiment was laid out in a Randomized Block Design (RBD) with eight treatments replicated three times, comprising a total of 24 plots. The gross plot size was 9.0 m × 6.0 m, and the net plot size varied according to treatment. The treatments consisted of eight plant spacings: T_1 - 30 cm × 7.5 cm (4,44,444 plants ha^{-1}), T_2 - 45 cm × 5 cm (4,44,444 plants ha^{-1}), T_3 - 45 cm × 10 cm (2,22,222 plants ha^{-1}), T_4 - 45 cm × 20 cm (1,11,111 plants ha^{-1}), T_5 - 45 cm × 30 cm (74,074 plants ha^{-1}), T_6 - 60 cm × 10 cm (1,66,666 plants ha^{-1}), T_7 - 60 cm × 20 cm (83,333 plants ha^{-1}), and T_8 - 60 cm × 30 cm (55,555 plants ha^{-1}).The gross plot size was 9.00 m × 6.00 m, while net plot dimensions varied according to the treatment layout. The experimental site featured a levelled and well-drained clay soil, characterized by moderate available nitrogen, medium phosphorus, and high potassium content. The soybean variety MAUS-725 was selected for the study, and sowing was carried out manually using the dibbling method on 4th July 2024. The treatment T_3 (45 cm × 10 cm) emerged as the most efficient geometry for maximizing growth and yield without compromising plant growth or seed quality. It provided an optimal balance between plant population and resource availability, leading to superior performance in most growth and yield parameters. Therefore, under the agro-climatic conditions of Parbhani, district of M.S, adopting a spacing of 45 cm × 10 cm is recommended for enhancing productivity and profitability in soybean cultivation. Further studies integrating spacing with nutrient and water management may offer additional insights for sustainable intensification.

Keywords: Growth attributes, Plant density, plant spacing, Soybean, Yield performance

Introduction
Among the pulses grown in India and Maharashtra soybean is an important crop. Soybean (*Glycine max* L. Merrill) is the most important legume crop in the family Leguminosae, sub-family Papilionaceae and genus Glycine. Soybean was cultivated in China as early as 3000 B.C. (Hymowitz, 1970) [4]. It has seen remarkable growth in production, processing and trade in recent years revolutionizing the rural economy and improving the socioeconomic condition of farmers (Singh *et al.*, 2013) [13].
It is a major oilseed crop that is widely used as a pulse, oilseed, vegetarian meat and in products such as soya milk. It is popularly known as the "Wonder Crop" or "Golden Bean" of the twenty-first century (Rani *et al.*, 2017) [12]. Soybean contains 40-42% protein and about 20% oil (Nagalakshmi *et al.*, 2003). It also comprises 30% carbohydrates, 5% minerals, 4-5% crude fiber, 0.5% lecithins and 4% saponins along with significant quantities of vitamins and amino acids. Soybean is a multipurpose crop primarily grown for edible oil extraction and also used in soya-based products like soya milk, paneer (tofu), yogurt, ice cream, butter and fortified foods. These products are widely accepted due to their nutritional and economic value (Gandhi and Zhou, 2014) [3]. Isoflavones in soybean also make it valuable in the cosmetic and medicinal industries as they help reduce the risk of cardiovascular diseases and diabetes (Messina, 1999) [7].
Soybean stands as the leading oilseed crop globally, both in terms of total oilseed and edible oil production. According to USDA estimates for 2022-23 global soybean production reached approximately 386 million metric tons, cultivated over an area of 130 million hectares, with an average yield of around 2970 kg ha^{-1}.

The top soybean-producing countries include Brazil, United States, Argentina and China while India holds the fifth position globally. In India during the 2023 *kharif* season soybean was cultivated over 12 million hectares, yielding about 12 million tonnes with an average productivity of approximately 1000 kg ha^{-1} (MAFW, Government of India, 2023). Major soybean-producing states in the country include Madhya Pradesh, Maharashtra, Rajasthan, Telangana, Karnataka and Chhattisgarh with Madhya Pradesh leading the way cultivating 5.20 million hectares and contributing about 5.24 million tonnes to national output (SOPA, 2023).

Materials and Methods

A field experiment was carried out to investigate the 'Influence of crop geometry on growth and yield of soybean (*Glycine max* L. Merrill)' at the Experimental Farm, Department of Agronomy, VNMKV, Parbhani.
Geographically, Parbhani has a semi-arid climate and is located at latitude 190 16' North and longitude 760 47' East. From June to December 2024, the Agricultural Meteorological Observatory recorded weekly meteorological data related to mean total rainfall, rainy days, maximum and minimum temperature, mean relative humidity, mean evaporation (mm), and mean bright sunshine hours per day of corresponding weeks that prevailed during crop growth. V.N.M.K.V. Parbhani receives 869.7 mm of rainfall throughout the crop growth period.

Experimental details

1. Name of crop : Soybean (*Glycine max* L. Merrill)
2. Varieties : MAUS -725
3. Design : Randomized block design (RBD)
4. Replication : 3
5. Number of treatments : 8
6. Number of plots : 24
7. Plot size : Gross - 9.00 m x 6.00 m
8. Net - as per treatment

Treatment Details

1. T_1- 30 cm x 7.5 cm (4,44,444 plants ha^{-1})
2. T_2- 45 cm x 5 cm (4,44,444 plants ha^{-1})
3. T_3- 45 cm x 10 cm (2,22,222 plants ha^{-1})
4. T_4- 45 cm x 20 cm (1,11,111 plants ha^{-1})
5. T_5- 45 cm x 30 cm (74,074 plants ha^{-1})
6. T_6- 60 cm x 10 cm (1,66,666 plants ha^{-1})
7. T_7-60 cm x 20 cm (83,333plants ha^{-1})
8. T_8- 60 cm x 30 cm (55,555 plants ha^{-1})

Results and Discussions

Plant height (cm)

Plant height of soybean was significantly influenced by planting geometry from 45 DAS onwards (Table 1). At 30 DAS, differences were non-significant, though T_1 (30 × 7.5 cm) recorded the tallest plants (19.18 cm), followed by T_2 (18.65 cm) and T_3 (18.20 cm), while T_8 (60 × 30 cm) showed the lowest height (15.23 cm).

Table 1: Mean plant height (cm) of soybean as influenced by crop geometry

Treatment	Plant height (cm)				
	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
T_1 (30 cm x 7.5 cm)	19.18	29.81	40.53	45.27	47.71
T_2 (45 cm x 5 cm)	18.65	28.46	39.15	43.66	46.04
T_3 (45 cm x 10 cm)	18.20	27.68	37.87	41.77	43.97
T_4 (45 cm x 20 cm)	17.10	23.40	33.45	36.77	38.34
T_5 (45 cm x 30 cm)	16.04	21.08	30.58	33.41	34.49
T_6 (60 cm x 10 cm)	17.51	25.17	35.34	38.82	40.58
T_7 (60 cm x 20 cm)	16.58	21.77	31.48	34.47	35.65
T_8 (60 cm x 30 cm)	15.23	19.41	28.68	31.01	31.64
SE. (m). ±	1.13	1.3	1.27	1.83	2.04
CD @ 5%	NS	3.92	3.85	5.53	6.16
G.M.	15.20	24.6	34.63	38.15	39.8

From 45 DAS onward, the effect became significant, with T_1 consistently producing the tallest plants (29.81, 40.53, 45.27, and 47.71 cm at 45, 60, 75 DAS and harvest, respectively), statistically at par with T_2 and T_3. Wider spacings such as T_4 and T_8 recorded shorter plants, with T_8 consistently the lowest across all stages.
Overall, closer spacings (T_1 and T_3) promoted taller plants due to stronger competition for light, triggering shade-induced elongation (Pierik *et al.*, 2004) [10]. Conversely, wider spacings (T_4 and T_8) resulted in shorter, bushier growth owing to better light penetration and reduced crowding. Thus, planting geometry played a key role in shaping soybean plant architecture and optimizing canopy structure for efficient resource use (Board & Kahlon, 2011; De Bruin & Pedersen, 2008).

Number of branches plant^{-1}

Planting geometry had a marked effect on branch development in soybean from 60 DAS onward (Table 2). At 45 DAS, though differences were non-significant, T_8 (60 × 30 cm) recorded the highest branches (4.47), followed by T_5 (4.07) and T_7 (3.67), while the lowest was in T_1 (1.67) under closed spacing. At 60 DAS, spacing effects became significant—T_8 (6.27) produced the most branches, statistically at par with T_5 (5.87), followed by T_7 (5.47) and T_4 (5.07), whereas T_1 (3.47) and T_2 (3.87) recorded the fewest.

Table 2: Mean number of branches plant^{-1} of soybean as influenced by crop geometry

Treatment	Number of branches per plant		
	45 DAS	60 DAS	75 DAS
T_1 (30 cm x 7.5 cm)	1.67	3.47	4.57

T_2 (45 cm x 5 cm)	2.07	3.87	4.97
T_3 (45 cm x 10 cm)	2.47	4.27	5.37
T_4 (45 cm x 20 cm)	3.27	5.07	6.17
T_5 (45 cm x 30 cm)	4.07	5.87	6.97
T_6 (60 cm x 10 cm)	2.87	4.67	5.77
T_7 (60 cm x 20 cm)	3.67	5.47	6.57
T_8 (60 cm x 30 cm)	4.47	6.27	7.37
SE. (m). ±	0.13	0.22	0.25
CD @ 5%	NS	0.68	0.76
G.M.	3.06	4.87	5.97

At 75 DAS, T8 (7.37) again showed the highest number of branches, comparable with T_5 (6.97), followed by T_7 (6.57) and T_4 (6.17), while T_1 (4.57) had the minimum. Overall, wider spacings (T_8, T_5, T_7) consistently promoted higher branching due to reduced competition and improved light and nutrient availability, whereas closer spacings (T_1 and T_3) restricted lateral growth. Hence, adopting optimal planting geometry enhances branching, a vital contributor to soybean yield potential (Patel *et al*., 2020) [9].

Number of leaves plant^{-1}

Planting geometry significantly influenced leaf production in soybean at various growth stages (Table 3). The number of leaves increased steadily with crop age, with wider spacings promoting greater leaf development due to reduced competition for resources (Kumawat *et al.*, 2015; Singh *et al.*, 2020) [14]. At 30 DAS, differences were non-significant, but T_8 (60 × 30 cm) recorded the highest leaf count (8.7), followed by T_5 (8.5) and T_7 (8.4), while T_1 (6.2) had the lowest. At 45 DAS, spacing effects became significant T_8 (16.5) produced the most leaves, statistically at par with T_5 (16.2), T_7 (15.9) and T_4 (15.5), while T_1 (12.5) recorded the minimum.

Table 3: Mean number of leaves plant^{-1} of soybean as influenced by crop geometry

Treatment	Number of leaves plant^{-1}			
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**
T_1 (30 cm x 7.5 cm)	6.2	12.5	19.1	21.4
T_2 (45 cm x 5 cm)	6.8	13	19.6	22
T_3 (45 cm x 10 cm)	7.4	14.3	21.2	24.1
T_4 (45 cm x 20 cm)	8.1	15.5	23.3	26.5
T_5 (45 cm x 30 cm)	8.5	16.2	24	27.2
T_6 (60 cm x 10 cm)	7.6	14.6	21.8	24.7
T_7 (60 cm x 20 cm)	8.4	15.9	23.6	26.8
T_8 (60 cm x 30 cm)	8.7	16.5	24.5	28
SE. (m). ±	0.34	0.64	0.92	1.06
CD @ 5%	**NS**	1.94	2.8	3.2
G.M.	7.71	14.81	22.13	25.08

At 60 DAS, T_8 (24.5) again showed the highest leaf number, comparable with T_5 (24.0), T_7 (23.6) and T_4 (23.3); the lowest was in T_1 (19.1). At 75 DAS, the trend persisted—T_8 (28.0) had the maximum leaves, statistically at par with T_5 (27.2), T_7 (26.8) and T_4 (26.5), whereas T_1 (21.4) remained lowest. Overall, wider spacings (T_8, T_5, T_7, T_4) consistently enhanced leaf development, reflecting improved light interception and resource use, while closer spacings (T_1 and T_3) restricted leaf proliferation due to crowding. Hence, adopting optimal planting geometry promotes canopy expansion, photosynthetic efficiency, and yield potential in soybean (Rana *et al*., 2014) [11].

Total dry matter plant^{-1} (g plant^{-1})

Planting geometry significantly influenced total dry matter accumulation in soybean across all growth stages (Table 4). At 30 DAS, differences were non-significant, though T_8 (60 × 30 cm) recorded the highest TDM (8.95 g plant^{-1}) followed by T_5 (7.10 g) and T_4 (6.85 g), while the lowest was in T_1 (3.50 g), indicating early suppression under dense planting. From 45 DAS onwards, spacing effects became significant. T_8 consistently produced the Highest dry matter (19.65, 32.60, 41.85, and 51.18 g plant^{-1} at 45, 60, 75 DAS and harvest, respectively), statistically comparable with T_5, and followed by T_4 and T_7. The lowest values were recorded in T_1 at all stages. Overall, wider spacings (particularly T_8: 60 × 30 cm) promoted greater dry matter accumulation due to reduced competition and improved light, nutrient and moisture availability, whereas denser spacing (T_1: 30 × 7.5 cm) restricted biomass buildup. Intermediate geometries such as T_5, T_4, and T_7 also performed well, suggesting that balanced spacing can optimize vegetative growth and total biomass production in soybean (Zhao *et al.*, 2009) [16].

Table 4: Mean Total dry matter plant^{-1} (g) of soybean as influenced by crop geometry

Treatment	Total Dry Matter per Plant (g/plant)				
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**	**Harvest**
T_1 (30 cm x 7.5 cm)	3.5	5.24	6.4	8.1	10.3
T_2 (45 cm x 5 cm)	3.8	5.85	9.15	10.2	12.7
T_3 (45 cm x 10 cm)	5.2	10.85	18.25	21.45	24.15
T_4 (45 cm x 20 cm)	6.85	16.15	25.45	36.25	45.35
T_5 (45 cm x 30 cm)	7.1	17.75	27.21	37.95	47.4
T_6 (60 cm x 10 cm)	5.9	11.8	19.65	22.13	26.2
T_7 (60 cm x 20 cm)	6.1	14.56	22.16	32.5	41.45
T_8 (60 cm x 30 cm)	8.95	19.65	32.6	41.85	51.18
SE. (m). ±	0.25	0.53	0.91	1.21	1.37
CD @ 5%	NS	1.60	2.75	3.65	4.14
G.M.	5.93	12.73	20.10	26.30	32.34

Number of pods plant^{-1}

Planting geometry had a significant effect on pod formation at all reproductive stages (Table 5). Pod number increased progressively from 60 DAS to harvest, with wider spacings supporting greater pod development per plant.

At 60 DAS, T_8 (60 × 30 cm) produced the highest pods (65.45), significantly superior to all other treatments, followed by T_4 (54.35) and T_5 (54.27). The lowest counts were recorded in T_1 (10.4) and T_2 (11.25), indicating that dense planting restricted pod initiation.

Table 5: Mean number of pods plant^{-1} of soybean as influenced by crop geometry

Treatment	Number of pods per plant		
	60 DAS	75 DAS	Harvest
T_1 (30 cm x 7.5 cm)	10.4	12.15	13.01
T_2 (45 cm x 5 cm)	11.25	13.65	14.1
T_3 (45 cm x 10 cm)	28.85	30.15	32.08
T_4 (45 cm x 20 cm)	54.35	56.4	58.85
T_5 (45 cm x 30 cm)	54.27	56.2	58.34
T_6 (60 cm x 10 cm)	28.54	30.1	32.45
T_7 (60 cm x 20 cm)	51.5	53.8	55.45
T_8 (60 cm x 30 cm)	65.45	67.16	69.89
CD @ 5%	1.58	1.81	1.85
SE. (m). ±	4.79	5.47	5.61
SE (d)	38.07	39.95	41.77

At 75 DAS, T_8 (67.16) maintained its superiority, followed by T_4, T_5, and T_7 (53.8-56.4 pods), while T_1 (12.15) and T_2 (13.65) remained lowest. At harvest, T_8 (69.89) again recorded the maximum pods, followed by T_4 (58.85), T5 (58.34), and T_7 (55.45), whereas T_1 (13.01) produced the fewest. Overall, wider spacings (T_8, T_4, T_5, T_7) consistently enhanced pod formation due to reduced interplant competition, improved light penetration, and better canopy aeration, while closer spacings (T_1, T_2) limited reproductive growth. These findings emphasize that optimum planting geometry is essential for maximizing pod production and yield potential in soybean.

Conclusions

The treatment T_3 (45 cm × 10 cm) emerged as the most efficient geometry for maximizing growth and yield without compromising plant growth or seed quality. It provided an optimal balance between plant population and resource availability, leading to superior performance in most growth and yield parameters. Therefore, under the agro-climatic conditions of Parbhani, district of M.S, adopting a spacing of 45 cm × 10 cm is recommended for enhancing productivity and profitability in soybean cultivation. Further studies integrating spacing with nutrient and water management may offer additional insights for sustainable intensification.

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