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Planting precision: Investigating the soybean growth dynamics with different varieties and planting geometries

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Abstract
In the 2022 *kharif* season, a field experiment was conducted at MARS, UAS, Dharwad to study the performance of soybean varieties (DSb 21, KDS 726 and KDS 753) across the different planting geometries (22.5 cm × 10 cm, 30 cm × 10 cm, 37.5 cm × 10 cm and 45 cm × 10 cm). Varieties and planting geometries interacted significantly, influencing soybean growth attributes. KDS 753 with 45 cm × 10 cm geometry recorded the highest number of branches (5.68), dry matter plant-1 (29.94 g) and canopy spread (34.33 cm). Additionally, KDS 753 with 30 cm × 10 cm geometry showed the highest leaf area index (4.82). However, KDS 753 with the narrowest geometry of 22.5 × 10 cm excelled in plant height (58.80 cm) and first pod height (13.45 cm) compared to other treatments. This result shows the impact of variety and planting geometry on soybean performance, emphasizing the significance of optimal combinations for enhanced growth attributes.

Keywords: Soybean, variety, geometry, growth attributes Dharwad

1. Introduction
Soybean (*Glycine max*), a major oilseed crop originated from East Asia, holds a critical role in Indian agriculture. Its global standing is complemented by its significance in India, characterized by nutritional richness, featuring 40-42% protein, 18-20% oil and 6.4% lysine content, along with essential vitamins and minerals (Pagano and Miransari, 2016) [26]. This crop not only acts as a nutritional powerhouse but also contributes ecologically by fixing atmospheric nitrogen (35-140 kg ha-1), reducing the reliance on synthetic fertilizers and enhancing soil fertility (Herridge *et al*., 2008) [13]. The adaptability of soybean to diverse climatic conditions positions it as a significant contender well-suited for the evolving environmental dynamics in the specific region (Novikova *et al*., 2020) [25].

Globally, soybean is the leading oilseed crop, contributing 61% of total production. In India, soybean is cultivated across 11.44 million hectares, yielding 12.04 million tons with productivity of 1052 kg ha-1 (Anon., 2022) [4]. Despite Brazil's production dominance, India's 3% contribution highlights its vital role in the nation's agriculture. Primary soybean-growing states include Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Karnataka and Gujarat. In Karnataka, soybean covers 0.43 million hectares, producing 0.44 million tons, holding crucial significance for India's edible oil production (Anon., 2022) [4].

Achieving optimal plant density is crucial for maximizing resource utilization (Acko and Trdan, 2009) [1]. Constraints on crop productivity, including genotypes and spacing, play a pivotal role (Dhaliwal and Kler, 1995) [9]. Challenges, such as farmers neglecting adapted varieties and row spacing, hinder optimal production. Cultivation of resistant, high-yielding varieties with appropriate planting geometry is essential for unlocking the maximum growth potential of soybean crops, particularly in the changing climatic conditions of the northern transition zone of Karnataka. Optimizing plant population and adopting suitable agronomic practices are pivotal for the enhancement of growth attributes (Billore *et al*., 2000; Ammaiyappan *et al*., 2023) [8, 2]. Early and medium maturity stress-resistant genotypes offer promising solutions. Based on the above facts, this research is conducted to identify the best combination of suitable variety with appropriate geometry to overcome the yield gap.

2. Materials and Methods

A field experiment was conducted during the *kharif* season 2022 at College of Agriculture, Dharwad, MARS, UASD. Twelve treatments comprising three varieties (DSb 21, KDS 726 and KDS 753) as main plot and four planting geometry (22.5 cm × 10 cm, 30 cm × 10 cm, 37.5 cm × 10 cm and 45 cm × 10 cm) as sub plot were laid out in split plot design to study the performance of soybean varieties under different planting geometries on northern transition zone of Karnataka. Throughout the crop growth period, the Main Agricultural Research Station, Dharwad received total rainfall of 574 mm over 37 rainy days. The average monthly relative humidity in July, August, September, October and November ranged from 58% to 87.1%, providing favorable conditions for crop growth. The mean maximum temperature fluctuated between 26.6 ˚C to 29.5˚C, while the minimum temperature ranged from 16.5 to 20.5˚C, both falling within the optimal temperature range (15-32˚C) for soybean cultivation. Meteorological data was obtained from the meteorological observatory at MARS Dharwad. The soil in the experimental field was clayey, with pH of 7.1, electrical conductivity (EC) of 0.33 dSm^{-1}, low in organic carbon content (0.45%), low in available nitrogen (265 kg ha-1), high in available phosphorus (30.6 kg ha-1) and potassium (368 kg ha-1). Crop was sown on 22nd July 2022, treating seeds with rhizobium and PSB culture @ 150 g per 10 kg of seeds. Recommended dose of fertilizer, *i.e.* 40:80:25 kg ha-1, N, P_2O_5 and K_2O, respectively is applied through urea, di-ammonium phosphate and muriate of potash. Crop growth parameters were observed by recording data from five randomly selected plants and the data were statistical analyzed applying the Analysis of Variance (ANOVA), in accordance with the methodology advocated by Gomez and Gomez (1984) [11].

3. Results and Discussion

3.1 Plant height (cm)

The plant height of soybean varieties is a crucial growth trait that influences various aspects of plant performance. Significant differences in plant height were observed due to genotypes. The soybean variety KDS 753 (56.59 cm) and KDS 726 (54.68 cm) recorded significantly higher plant height compared to DSb 21 (49.26 cm). The observed variations in plant height among the soybean varieties can be attributed to inherent differences in their genetic characteristics and composition. This disparity in genetic makeup likely contributes to the efficient utilization of available resources, such as nutrients, water and sunlight. Additionally, the adaptability of each variety to specific climatic conditions may play a crucial role in determining their vertical growth. Singh (2011) [31], Varsha *et al.* (2020) [36] and Anusha *et al.* (2021) [6] also documented differential responses among soybean varieties with respect to plant height.

The highest plant height of soybean was observed under the narrowest spacing of 22.5 cm × 10 cm (55.66 cm) which was at par with the geometry level of 30 cm × 10 cm (54.40 cm) and 37.5 cm × 10 cm (52.62 cm). While, the lowest plant height was recorded under the widest planting geometry of 45 cm x 10 cm (51.37 cm). Taller plant in narrower spacing might have resulted due to higher competition for sunlight than those of wider spacing plants because of densely population in narrow spacing. These views were supported by Meena *et al*. (2017) [21] who reported that the positive relationship of closer spacing on plant height might be attributed to high inter-plant competition, which caused internodal elongation and also similar results were reported by Malek *et al*. (2012) [20] and Rahman and Hossain (2013) [28].

The interaction between the varieties and planting geometry was found to be significant regarding the plant height of soybean. Among the treatment combinations, significantly higher plant (58.80 cm) was observed with genotype KDS 753 when sown at spacing of 22.5 cm × 10 cm which was at par with the same variety at planting geometry of 30 cm × 10 cm (57.55 cm). While, the variety DSb 21 along with planting geometry of 45 cm × 10 cm recorded lowest plant height. The interactive effects on plant height resonate with the findings of Khaire *et al*. (2020) [18], emphasizing the importance of specific combinations of varieties and planting geometries in influencing plant height synergistically.

3.2 Number of branches per plant

Significantly higher number of branches per plant (5.47) of soybean was observed with the variety KDS 753 whish was statistically similar with KDS 726 (5.02). While, the lowest number of branches per plant (4.85) was recorded by DSb 21. The genetic influence on the number of branches is evident, with KDS 753 consistently exhibiting the highest number. This aligns with the studies conducted Nayak *et al*. (2020) [24] and Saha and Islam (2022) [30], highlighting the pivotal role of genetic diversity in shaping soybean branching patterns.

The number of branches per plant exhibited a distinct pattern across different planting geometries. Notably, as the spacing widened, there was an increase in the number of branches. For instance, the narrowest spacing (22.5 cm × 10 cm) resulted 4.87 branches per plant, while geometry level of 45 cm × 10 cm displayed the highest number of branches, reaching 5.46. This observed trend aligns with the principles discussed by Mahapatra and Shah (2020) [19], suggesting that wider spacing tends to promote increased lateral branching, likely due to reduced competition for resources.

The number of branches of soybean was significantly affected by the interaction between varieties and planting geometries. Soybean variety KDS 753 sown with the planting geometry of 45 cm × 10 cm recorded highest number of branches (5.68) compared to other treatment combinations. The significant impact of both variety and row spacing on the number of branches underscore the distinct response of varieties to varying row spacing conditions. This finding aligns with the research conducted by Kena (2018) [17], who observed increased number of branches with wider plant spacing.

Table 1: Growth parameters of soybean influenced by varieties and planting geometry

Treatments	Plant height (cm)	Number of branches plant-1	Canopy spread (cm)	Dry matter plant-1 (g)	Leaf area index	First pod height (cm)
Main plot (M): Varieties						
M1: DSb 21	49.26b	4.85b	29.66b	18.57b	2.90b	10.13b
M2: KDS 726	54.68a	5.02ab	33.00a	24.01a	3.16a	11.34ab
M3: KDS 753	56.59a	5.47a	34.11a	25.88a	3.36a	12.40a
S.Em. ±	1.53	0.16	1.02	0.73	0.08	0.45
Sub plot (S): Geometry						
S1: 22.5 cm × 10 cm	55.66a	4.87b	29.78b	18.86b	2.13c	12.63a
S2: 30 cm × 10 cm	54.40ab	4.99ab	31.08ab	20.88b	4.45a	12.00a
S3: 37.5 cm × 10 cm	52.62ab	5.13ab	32.35ab	25.28a	3.45b	11.47a
S4: 45 cm × 10 cm	51.37b	5.46a	33.82a	26.26a	2.53c	9.05b
S.Em. ±	1.32	0.16	1.23	0.84	0.11	0.5
Interaction: (M × S)						
M1S1	51.32c-e	4.58e	26.80e	15.38g	2.06f	11.7a-c
M1S2	49.97de	4.71de	28.15de	16.84fg	4.02b	10.3c-e
M1S3	48.48e	4.84c-e	28.50b-e	20.69de	3.07d	10.25c-e
M1S4	47.26e	5.26a-e	29.2c-e	21.37de	2.45ef	8.25e
M2S1	56.85ab	4.72de	30.80b-e	19.77ef	2.13f	12.75a
M2S2	55.67a-c	4.88b-e	32.40a-d	22.31de	4.51a	12.4ab
M2S3	53.87a-d	5.03a-e	33.70a-c	26.48bc	3.45cd	11.75a-c
M2S4	52.34b-e	5.45a-c	35.10ab	27.46ab	2.53ef	8.45de
M3S1	58.80a	5.32a-d	31.75b-e	21.42de	2.19ef	13.45a
M3S2	57.55ab	5.37a-d	32.70a-d	23.49cd	4.82a	13.3a
M3S3	55.51a-c	5.53ab	34.85ab	28.68ab	3.82bc	12.4ab
M3S4	54.50a-d	5.68a	37.15a	29.94a	2.61e	10.46b-d
S.Em. ±	2.29	0.28	2.13	1.46	0.19	0.87

*****Means followed by the same alphabet (s) within a column are not significantly differed by DMRT (P=0.05)

3.3 Canopy spread

Among the varieties, KDS 753 exhibited significantly higher canopy spread (34.11 cm) compared to DSb 21 (29.66 cm), but it was statistically similar to KDS 726 (33.00 cm). The distinctive genetic traits of soybean varieties, particularly the observed increase in the number of branches in cultivars like KDS 26 and KDS 753, influenced the spatial distribution of the canopy. This inherent characteristic, contributing to more extensive branching system, played significant role in the observed increase in canopy spread.

Canopy spread exhibited significant variations across different planting geometries. Notably, as the spacing widened, there was an increase in canopy spread. For instance, geometry level of 22.5 cm × 10 cm resulted lowest canopy spread (29.78 cm), while, widest plant geometry 45 cm × 10 cm displayed the highest canopy spread (33.82 cm). This observed trend aligns with existing research, as studies by Malek *et al*. (2012) [20] and Angadi (2016) [3] suggest that wider spacing tends to promote increased canopy spread, likely due to reduced competition for resources.

Significant difference in canopy spread of soybean was observed due to interaction between varieties and planting geometries. Among the treatment combinations, significantly higher canopy spread plant-1 (37.15 cm) was observed with variety KDS 753, when sown at spacing of 45 cm × 10 cm which was on par with the same variety at geometry of 37.5 cm x 10 (34.85 cm).

3.4 Dry matter per plant

The dry matter per plant of soybeans, presented in Table 1, exhibited notable variations among the varieties. DSb 21 recorded lowest dry matter production per plant of 18.57 g, whereas KDS 726 displayed substantial increase at 24.01 g and KDS 753 consistently exhibited the highest dry matter production per plant (25.88 g). Notably, the observed distinctions in dry matter accumulation align with genetic traits that favour enhanced biomass development, characteristics prominently demonstrated by KDS 753 and KDS 726. These genetic traits, including higher number of branches and increased canopy spread, contributed to the overall robustness of these varieties, emphasizing their potential for maximizing biomass production. These findings lend support to those previously reported by Rahman and Hossain (2013) [28], Raghuwanshi *et al*. (2017) [27] and Keisham *et al*. (2021) [16].

The planting geometry of 45 cm × 10 cm yielded the highest dry matter production plant-1 (26.26 g), which was comparable to that of 37.5 cm × 10 cm (25.28 cm). In contrast, the spacing of 22.5 cm × 10 cm resulted the lowest dry matter production per plant across all stages. This result might be due to wider spacing, facilitated by ample light, moisture, favourable source-sink relationship and enhanced nutrient availability, could lead to greater number of branches per plant. This, in turn, might contribute to broader canopy spread, ultimately leading to increased dry matter production per plant. Similar results were also reported by Malek *et al*. (2012) [20], Angadi (2016) [3] and Verma *et al*. (2020) [37].

Significant difference in dry matter production plant-1 was recorded due to the interaction between varieties and planting geometries. Among the treatment combinations variety KDS 753 along with the planting geometry of 45 cm × 10 cm recorded significantly higher dry matter plant-1 (29.94 g) compared to other treatment combinations. However, it was on par with same variety at 37.5 cm × 10 cm (28.68 g) and 30 cm × 10 cm (23.49 g). Meena *et al*. (2017) [21] and Smith *et al*. (2022) [33] also reported significance difference in dry matter production due to varieties and planting geometry.

3.5 Leaf area index

The results indicate significant influence of soybean varieties on the leaf area index (LAI). Specifically, soybean varieties, such as KDS 753 (3.36) and KDS 726 (3.16), recorded substantially higher LAI compared to DSb 21 (2.90). This heightened LAI in KDS 753 and KDS 726 can be attributed to their superior canopy spread, a crucial determinant fostering more expansive and efficient leaf arrangement for photosynthetic processes. The ability of these varieties to support greater number of leaves promotes enhanced energy capture, subsequently driving robust growth. This phenomenon contributed to the observed increase in LAI. These findings resonate with the results reported by Vyas and khandwe (2014) [38] and Nath *et al*. (2017) [23].

Planting geometry of 30 cm × 10 cm exhibited the highest leaf area index (4.45), followed by 37.5 cm × 10 cm (3.45) and 45 cm × 10 cm (2.53). Meanwhile, geometry of 22.5 cm × 10 cm had the lowest value of leaf area index (2.13). Planting arrangement of 30 cm × 10 cm displayed the highest leaf area index, which consistently decreased with increasing spacing. These findings align with Ibrahim (1996) [14] who found a similar trend of wider row spacing leading to decreased leaf area index. Sivakumar *et al*. (2018) [32] also reported highest leaf area index under the geometry of 30 cm × 10 cm.

The leaf area index of soybean found to be significant due to interaction between varieties and planting geometry. Among the treatment combinations, the variety KDS 753 along with the geometry level of 30 cm × 10 cm recorded highest leaf area index (4.82). Comparable result was noticed by Naik *et al*. (2017) [22].

3.6 First pod height

First pod height of soybean influenced significantly due to different varieties. First pod height of soybean varieties (KDS 753, KDS 726 and DSb 21) recorded to be 12.40 cm, 11.34 cm and 10.13 cm, respectively.

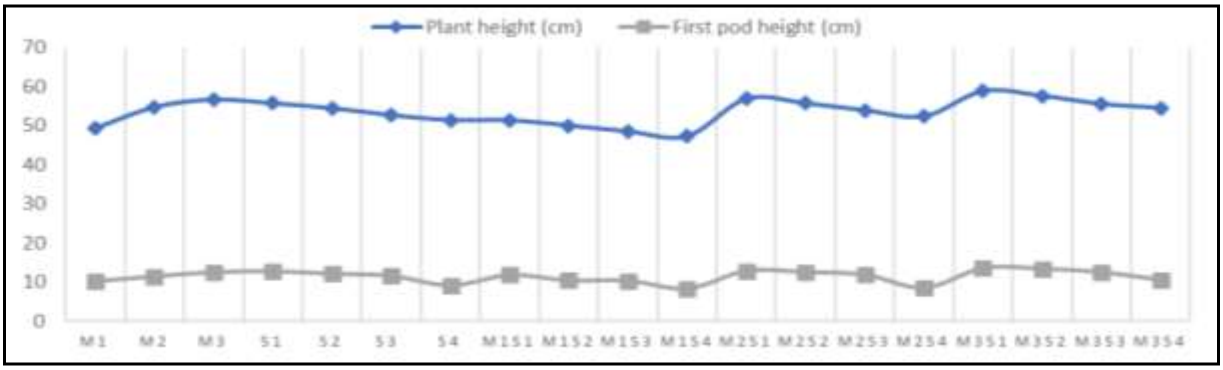

Fig. 1: Plant and first pod height of soybean influenced by varieties and planting geometries

Previous results have indicated that drastic harvest losses occurred at a height of first pod height below 7.5 cm (Epler and Staggenborg, 2008) [10]. In our study, each variety examined displayed the commencement of first pod development at stem height exceeding 10 cm, thereby reducing the risk of harvest loss associated with the initial pod's distance from the soil surface. These outcomes align with the observations reported by Sobko *et al*. (2020) [35].

The height of the first pod of soybean significantly influenced by different planting geometries. The height of the first pod plays a significant role in mechanical harvesting, as noted by Baig *et al*. (2014) [7]. Rębilas *et al*. (2020) [29] reported that low sowing densities in soybean plants lead to the development of pods set at lower height, which may result in yield losses during combine harvesting. Among the various levels of crop geometry tested in our study, spacing of 22.5 cm × 10 cm recorded significantly higher height for the first pod (12.63 cm), which was on par with the spacing of 30 cm × 10 cm (12 cm). However, all geometry levels except for 45 cm × 10 cm (9.05 cm) showed first pod height greater than 10 cm. Consequently, they posed lower risk of harvest loss due to the distance of the first pods from the soil surface, rendering them suitable for mechanical harvesting. Remarkably similar results were also documented by Gulluoglu *et al*. (2017) [12]. It has been observed that the height of the first pod increases with the overall height of the plant as shown in figure 1. Anuradha *et al*. (2014) [5] and Jańczak-Pieniążek *et al.* (2021) [15] also reported a positive correlation between plant height and basal pod height. This increase is particularly noticeable under narrow spacing, while it decreases with greater spacing.

Significant interactions were observed between varieties and planting geometries regarding soybean first pod height. Within the treatment combinations, KDS 753, particularly with narrow spacing of 22.5 cm × 10 cm and 30 cm × 10 cm, exhibited notably higher first pod heights at 13.45 and 13.30 cm, respectively, compared to other treatments. Across all varieties in our study, the first pod height exceeded 10 cm for various geometry levels, except in the case of the widest spacing of 45 cm × 10 cm. This implies that all varieties, in conjunction with different planting geometries, except the widest spacing of 45 cm × 10 cm, are at low risk of pod damage or yield loss during mechanical harvesting. These findings are consistent with earlier research, including the study conducted by Soares *et al*. (2015) [34].

4. Conclusion

In conclusion, this study aimed to enhance soybean cultivation in the northern transition zone of Karnataka, India, by considering different varieties and planting geometries. The results highlighted the significant impact of genetic traits and planting configurations on various soybean growth parameters. KDS 753 emerged as the most promising variety, demonstrating superior performance with increased plant height, higher number of branches, and enhanced canopy spread. The planting geometry of 45 cm × 10 cm consistently outperformed in various growth aspects, indicating robust soybean development. However, specific traits such as plant height, leaf area index and first pod height favored the 30 cm × 10 cm geometry, making it a suitable choice for mechanical harvesting.

For optimal soybean cultivation in the northern transition zone of Karnataka, the most favourable approach involves planting the variety KDS 753 with spacing of 45 cm × 10 cm, primarily for effective manual harvesting. It's important to note that this spacing is less suitable for mechanical harvesting due to specific considerations

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