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Optimization of intense plant to plant spacing of soybean [*Glycine Max* (L.) Merrill] for better productivity and quality seeds in the Western Himalayas

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Abstract

At the Pantnagar's Crop Research Centre, a field experiment was conducted during the 2019 *Kharif* season with the objective to establish the best plant-to-plant spacing for the PS 1092 and SL 958 soybean cultivars, which were developed especially for the western Himalayan region. The goal of the study was to determine how variable plant-to-plant spacing affected a variety of factors, including soybean production attributes, yield parameters, and quality metrics, particularly when ridge and furrow planting schemes were taken into consideration. The field experiment was laid out in a split-plot design, with four plant-to-plant spacing intervals (5 cm, 10 cm, 15 cm, and 20 cm) and two cultivars (PS 1092 and SL 958). Intense spacing treatments exhibited a discernible influence on soybean seed yield, stover yield, and total biological yield. The configuration of 45 cm × 10 cm spacing resulted in heightened productivity, showcasing maximal seed yield, stover yield, and total biological yield in comparison to alternative treatments. Furthermore, the stringent spacing regimens significantly impacted the quality parameters of soybeans. The protein content and oil content reached their zenith within plots featuring a plant-to-plant spacing of 10 cm. Intriguingly, no noteworthy differences surfaced in terms of productivity and quality parameters between the two soybean varieties. In summation, this study deduces that for achieving heightened productivity and superior quality of soybean varieties, PS 1092 and SL 958, in the *Tarai* conditions of the Western Himalayas, the recommended spacing of 45 cm × 10 cm holds promise.

Keywords oil content, protein content, soybean, spacing, variety

Introduction

Soybean (*Glycine max* (L.) Merrill) plays a pivotal role in global agriculture, offering valuable protein and edible oil resources with 15 to 22 percent and 36 to 45 percent oil content and protein content in its seed, respectively [1]. Nevertheless, India's soybean production remains modest, owing to a confluence of genetic, environmental, and agronomic factors. The suboptimal management of agronomic practices and a dearth of advanced interventions contribute to the existing disparity between national and global "Golden Bean" productivity. Among these factors, the strategic arrangement of plant-to-plant spacing, customized to specific varieties, emerges as a critical non-monetary input significantly influencing both soybean yield and quality across diverse agro-climatic contexts [2]. Optimizing spacing enhances the efficient use of resources, thereby elevating yields and overall crop quality.

Intense spacing, a practice involving reduced interplant distances, exhibits considerable potential in bolstering soybean productivity. This approach mitigates interspecific competition by lesser weed proliferation [3, 4] and maximizes light penetration by better crop canopy coverage at all the growth stages [5]. Consequently, soybean plants cultivated with closer spacing often surpass plants grown at wider spacing in terms of performance [6, 7]. The leaf area index (LAI) value is larger when soybeans are densely planted into narrow rows [8–9], and a rise in the LAI value as a result of a higher plant population density or intense plant spacing may increase seed production [10]. However, plants grown with extremely intense spacing, result in the decline of productivity and quality due to very high intraspecific competition for inputs and resources [11]. Therefore, identifying the optimal plant-to-plant spacing is called for to attain maximal yield. Optimum spacing can vary based on the cultivar and location. Varieties' distinctive responses to agronomic practices are shaped by the microclimate and field location, intricately linked to their genetic composition [12]. Thus, a tailored exploration of specific plant-to-plant distances is imperative for individual soybean varieties.

In the western Himalayas, where soybean predominantly relies on rainfed conditions, ensuring consistent moisture availability during the growth season presents a challenge. The preference for ridge planting in the *Tarai* region, aimed at facilitating germination during intense monsoons and maintaining optimal moisture levels throughout crop growth, underscores the significance of suitable planting methodologies. The improved emergence, enhanced crop growth, and root development in the ridge and furrow method led to an 8.7% higher grain yield compared to flat sowing and a 6.4% increase compared to raised bed sowing [13]. Bearing these considerations in mind, our study was designed to ascertain the optimum intense plant-to-plant spacing for soybean varieties SL 958 and PS 1092 within a ridge and furrow planting system. Our investigation seeks to provide insights that can enhance both yield and quality production.

Methodology

The location of the field experiment was G.B. Pant University of Agriculture and Technology in Pantnagar, Uttarakhand, India. Positioned at an elevation of 243.8 meters above mean sea level, with coordinates of 29° N latitude and 79.5° E longitude, this location set the stage for the study during the *kharif* growing seasons of 2019-20. Before this research initiative, the experimental site underwent wheat cultivation. The site boasted a pH of 6.8, enriched with 1.18% organic carbon, 230 kg/ha of readily available nitrogen, 22.5 kg/ha of P_2O_5, and 132 kg/ha of K_2O that was readily available.

The experiment involved the comparison of eight treatments, organized within a split-plot design and replicated thrice to minimize experimental error. In the main plot treatments, two soybean cultivars, PS-1092 and SL-958, were employed. The subplot treatments included four distinct plant-to-plant spacing intervals (5 cm, 10 cm, 15 cm, and 20 cm). To facilitate planting, manual creation of ridges was undertaken in the field, with ridges spaced at 45 cm and a ridge height set at 15 cm. Thiram 75% WP was applied to soybean seeds at a rate of 2 grams per kilogram of seed, coupled with Bavistine (Carbendazim 50% WP) at a rate of 1.0 grams per kilogram of seed. Subsequently, the seeds were inoculated with *Bradyrhizobium japonicum* culture at a rate of 500 g per 75 kg of seed. Following the creation of furrows within the ridges to a depth of 5 cm, sowing took place. Thinning was conducted after emergence (10 DAS) to ensure consistent intra-plant spacing and plant population in line with the treatment procedure. During the harvest, each plot's net plot area was used to record the yield and other relevant data. The reported yield was then translated to kilos per hectare. Protein content in grains was determined by multiplying the grain's nitrogen content by a factor of 6.25. Protein yield was calculated by multiplying protein content with the corresponding grain yield. Oil content was determined using the Soxhlet Extraction apparatus with petroleum ether as the extractant, and oil yield was reported in kg/ha as a product of oil content and seed yield.

The data obtained for various parameters underwent analysis of variance with mean comparisons at a 5% level of significance using OPSTAT, MS Excel, and R software. The test of significance for treatment differences relied on the 'F' test [14].

Results and Discussion

Number of branches, number of pods, seed index

Variety PS 1092 exhibited a significantly higher number of branches per plant compared to SL 958. The total number of branches in a plant was not significantly affected by the spacing at a 5 percent level of significance. Reduced intra-row spacing led to a decrease in the number of branches per plant, whereas a plant-to-plant spacing of 15 cm resulted in the highest number of branches per plant. This observation aligns with the findings reported by Abeje et al., [15]. The maximum number of branches per plant was produced by wider plant spacing, whilst the smallest number of branches per plant was produced by more compact spacing. These results are consistent with different researchers (7, 16-21).

In response to changes in spacing, the number of pods per plant comes out as a critical characteristic affecting soybean production [18]. Increased soybean yield per plant is correlated with a higher pod count per plant [9, 22]. According to this experiment, there were significantly fewer pods per plant as plant-to-plant distance decreased [23]. It's interesting to note how the quantity of pods is impacted by plant-to-plant spacing. Similar findings were also reported by researchers all across the globe [15, 18-20, 24-25]. Gulluoglu et al., [17] in their experimental findings reported 79% more pods per plant in widely spaced plants than the narrowly spaced plants. Variety PS 1092 had a higher count of number of pods per plant than SL 958, although the difference was not statistically significant. Variety PS 1092 and SL 958 had statistically comparable seed indexes. The effects of spacing treatments on seed index were not significant, consistent with the findings of Joshi et al., [26].

Soybean plants sown at wider spacing have in low population per unit area and therefore, produce more branches, and more pods [27]. In the same way, soybean plants at intense spacing have a higher population per unit area, produce fewer branches, and less number pods [27].

Seed yield

Variety PS 1092 demonstrated higher productivity with a seed yield of 1507 kg/ha, compared to SL 958 (1495 kg/ha) although the difference between the two was non-significant (Table 1). Among the tested plant spacing, the 10 cm spacing resulted in the highest seed production (1948.7 kg/ha), followed by 5 cm spacing (1568 kg/ha), the latter was statistically at par with the seed yield at 15 cm spacing (1372 kg/ha). The lowest yield was recorded at a 20 cm plant-to-plant spacing (1115 kg/ha). This aligns with the findings of Daramola et al., [3], Thompson et al., [11], Abeje et al., [15] Gulluoglu et al., [17] and Schmitz et al., [28] who suggest narrow spacing may provide higher seed yields of soybean than wider spacing. A remarkable 74.7% surge in seed yield is noticed when plant-to-plant spacing gets reduced from 20 cm to 10 cm. This enhancement in seed yield may be attributed to increased plant population and reduced inter-specific competition (by weeds) at 10 cm plant-to-plant spacing, which consequently resulted in higher yield per unit area. The same pattern of increasing yield with reducing spacing continues as yield increases by about 41.9% with a decrease in plant spacing from 15 cm to 10 cm. The reduction in intra-plant spacing from 20 to 10 cm led to a consistent increase in seed yield per hectare (Table 1). Narrowing the row spacing contributes to greater light absorption and increased canopy leaf area. These alterations in canopy formation accelerate crop development and the accumulation of dry matter, ultimately enhancing seed yield,

Table 1. Yield and yield attributes of soybean as influenced by different spacing and varietal treatments

Treatments	No. of branches per plant at harvest	No. of pods per plant at harvest	Seed Index (g)	Seed yield (kg/ha)	Stover Yield (kg/ha)	Total biological yield (kg/ha)	Harvest index (%)
Varieties							
PS 1092	3.5	66.9	6.9	1507.3	3370.1	4877.4	31.3
SL 958	2.5	63.2	7.2	1495.2	3266.0	4761.2	31.6
SEm ±	0.1	3.2	0.1	68.2	221.4	281.2	0.3
CD at 5%	0.6	NS	NS	NS	NS	NS	NS
Spacing (cm)							
45 x 5	2.7	57.0	7.2	1568.7	3762.2	5330.7	29.6
45 x 10	2.9	63.3	7.3	1948.7	4264.8	6213.3	31.4
45 x 15	3.3	68.8	6.5	1372.5	2941.3	4313.8	31.9
45 x 20	3.1	71.1	7.2	1115.2	2303.8	3419.3	33.0
SEm ±	0.2	5.8	0.2	70.3	209.0	262.4	1.0
CD at 5%	NS	NS	NS	219.0	651.3	817.8	NS

as highlighted by the findings [29]. However, decreasing the plant-to-plant spacing further, from 10 cm to 5 cm in the experiment resulted in a 19.5 % decrease in seed yield. This indicates, that as spacing decreases soybean yield is assumed to increase up to a certain point [7], after which yield decreases as further spacing is decreased. In general, soybean yield tends to rise as spacing decreases until reaching a certain point. Beyond this threshold, the yield may either stabilize or decline [27]. This stabilization or decline in yield is due to the competition effect between the soybean plants and the extent of vegetative growth and development of crops [27].

The lowest seed yield was reported from the widest spacing of 20 cm (Figure 1) as was also reported by Iyorkaa et al., [20] and Kumagai [30].

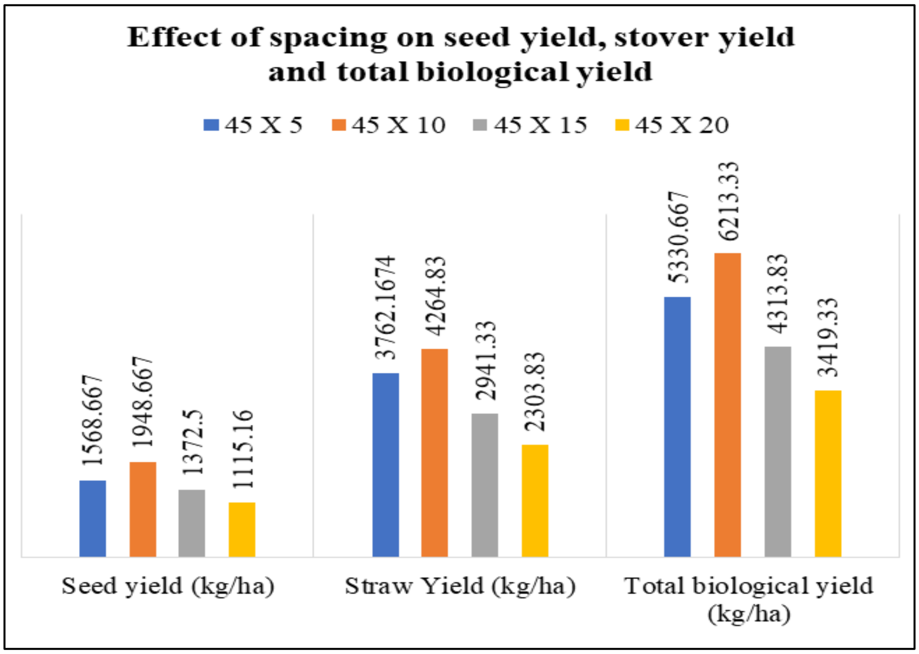

Figure 1. Effect of spacing treatments on yield (kg/ha) of soybean

This may be due to two specific reasons: - Firstly, a lower plant population maintained at wider spacing decreased the seed yield significantly. Secondly, wide spacing between plants gives way to rigorous inter-specific competition from weeds which ultimately decreases the yield [4]. According to research by Schutte and Nleya [31], narrower spacing results in a small 3-7% increase in soybean seed production in the United States. However, research [8] shows that in Germany, reduced spacing is accompanied by a notable increase in soybean output.

Stover yield and total biological yield

Variety PS 1092 boasted a higher stover yield compared to SL 958, although not with significant differences. The stover yield is significantly affected by the plant-to-plant spacing with 10 cm intra-row spacing yielding the maximum and 20 cm intra-row yielding the minimum. As spacing decreased from 20 cm to 10 cm stover yield increased by whooping 85.1 per cent. With the change in plant-to-plant spacing from 15 to 10 cm stover yield increased by about 44.9 percent. The dry matter yield increased with decreasing spacing as was also suggested by Hilena [32]. More intense spacing than 10 cm resulted in tough competition between soybean plants for resources and inputs and resulted in decreased stover yield. The total biomass yield of PS 1092 outperformed SL 958 with non-significant differences. Total biomass yield was significantly influenced by spacing treatments. The highest biomass production was from the close spacing of 10 cm and the least biomass production was from the wide spacing of 20 cm. Similar findings were also reported by Cox and Cherney [7], Abeje et al., [15] Gulluoglu et al., [17], Worku and Astatkie [21], and Chauhan and Opena [33]. Reducing plant-to-plant spacing from 20 cm to 10 cm significantly increased the total biological yield by 81.71 percent. At shift of spacing from 10 cm to extremely intense spacing of 5 cm total biological yield decreased by 14.2 per cent. The harvest index remained relatively unaffected by genotype variation and change in spacing.

Oil and protein content

In the experiment, the effect of spacing on oil content and protein content was studied for variety SL 958 and PS 1092. Both the varieties had almost equal content of oil and protein with no statistical differences (Table 2). A significant response was obtained for the effects of plant-to-plant spacing on the oil and protein content of soybean. In contrast, Sobko et al., [8] and Popovic et al., [34] reported that protein and oil content were not affected by spacing. Plants grown at an intra-row spacing of 5 cm, reported the minimal oil and protein content, due to poor nitrogen content and sulfur content in the seeds (data not given). This suggests that extremely intense spacing in soybeans creates a tough competitive environment for plants, reducing the nutrient uptake by individual plants. Therefore, poor-quality soybean seeds with less protein and oil content were obtained when plant-to-plant spacing was maintained at 5 cm. Crop sown at a spacing of 10 cm reported the maximum oil content which only decreased with further increase in spacing. A 4.5 percent and 5 percent reduction in oil content was observed with the increase in plant-to-plant spacing from 10 cm to 15 cm and 10 cm to 20 cm, respectively. Protein content was found to be the highest when soybean seeds were placed at 10 cm distance apart, which may be attributed to the reason that nitrogen content was reported to be the highest in the plots with 10 cm plant-to-plant spacing (data not given). With further increase in spacing from 10 cm to 15 cm and 10 cm to 20 cm protein content in seeds decreased by 5.2 percent and 4.8 percent respectively. On the other hand, Gulluoglu et al., [17] reported non-significant changes in the oil and protein content of soybean seed with the change in spacing.

Oil and protein yield

Protein yield and oil yield were found to be statistically indifferent to the varietal effect. Contrary to the varietal effect, the effect of the spatial distribution of plants had a significant effect on oil yield and protein yield. The maximum oil yield and protein yield were reported from plots with plant-to-plant

Table 2. Nutrient, oil, and protein content of soybean as influenced by different spacing and varietal treatments

Treatments	Oil Percentage	Oil yield (kg/ha)	Protein Percentage	Protein yield (kg/ha)
Varieties				
PS 1092	18.9	284.5	39.5	596.5
SL 958	19.2	289.1	40.3	598.6
SEm ±	0.1	12.9	0.2	2.1
CD at 5%	NS	NS	NS	NS
Spacing (cm)				
45 x 5	18.5	289.4	39.0	625.2
45 x 10	19.9	386.8	41.6	779.6
45 x 15	19.0	260.5	39.4	551.0
45 x 20	18.9	210.3	39.6	434.4
SEm ±	0.2	13.0	0.3	25.3
CD at 5%	0.6	40.5	1.0	78.7

spacing of 10 cm. Hilena [32] in her experimental findings also concluded that narrow spacing resulted in higher protein yields per hectare. The plots with higher protein yields were the same that reported the highest seed yield too, owing to increased protein yields. The lowest protein and oil yield were reported from the widest spacing of 20 cm (Figure 2). Low seed yield and poor nutrient uptake (nitrogen and sulfur) by plants at wider spacing may have contributed to low oil and protein yield at wider spacing. In line with these observations, Flajsman et al., [35] also concluded that spacing exerted a marked influence on seed, protein, and oil yields. They reported that soybean plants in narrow spacing generate higher yields with better oil and protein content than those in wider spacing.

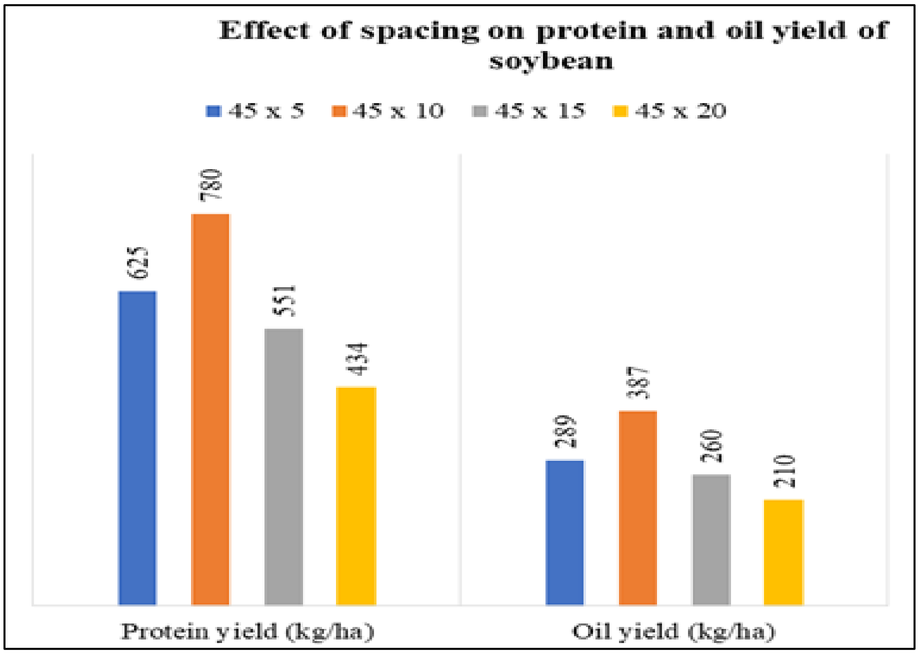

Figure 2. Effect of spacing treatments on protein and oil yield of soybean

Conclusion

Based on the findings of the experiment conducted, it can be deduced that a plant-to-plant spacing of 10 cm is optimal for sowing soybean. This spacing enables higher productivity alongside better-quality seeds. In terms of yield, oil yield, and protein yield, SL 958 exhibited a performance very similar to the variety PS 1092. Thus, for ridge sowing of varieties SL 958 and PS 1092 in the *Tarai* conditions of the Western Himalayas, a plant-to-plant spacing of 10 cm is recommended for achieving enhanced productivity, augmented protein content, and increased oil yield in soybean.

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Conclusion

The authors state they have no competing interests in this work.

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