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Growth, Rainfall Use Efficiency and Economics of Soybean [*Glycine max* (L.) Merrill] Varieties as Influenced by Intense Spacing under Ridge and Furrow Planting System in Western Himalayas

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ABSTRACT: In the face of limited resources and changing climatic conditions, a major challenge for agriculturists is to ensure food security while addressing the issue of an ever-growing population. To meet these challenges, optimization of agronomic practices for better growth and input use efficiency can be a solution. Strategic selection of appropriate varieties and spacing arrangements can enhance growth and ensure sustainable soybean cultivation practices. A field experiment was conducted during the kharif season of 2019–20 at GBPUAT, Pantnagar, to investigate the impact of intense spacing within the ridge and furrow planting system on growth, rainfall use efficiency, and economic aspects of soybean. The study encompassed two soybean varieties (PS 1092 and SL 958) and four plant-to-plant spacing treatments (5 cm, 10 cm, 15 cm, and 20 cm) arranged in a split-plot design. Results indicated that variety SL 958 exhibited significantly greater height compared to PS 1092 throughout various growth stages. Dry matter accumulation peaked with a plant-to-plant spacing of 20 at 60, 75, and 90 days after sowing. A spacing of 10 cm demonstrated significantly higher rainfall use efficiency (RUE), indicating optimum use of resources at closer spacing. Economically, soybean cultivation within the ridge and furrow system proved profitable when plant-to-plant spacing of 10 cm was employed. Overall, intense spacing of 10 cm emerged as the optimal choice for varieties SL 958 and PS 1092 in the context of both growth and economics. This study thus shows that better growth, higher RUE, and economic viability of soybean can be achieved by cultivating them in intense spacing under ridge and furrow planting system, in the western Himalayan region.

Keywords: CGR, PS 1092, RGR, RUE, SL 958, Soybean, Spacing, Variety.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) cultivation emerges as a promising avenue, offering a versatile solution to enhance food supply and livelihoods. The cultivation of "wonder crop" promises agricultural sustainability, productivity and profitability. Among the innovative practices aimed at addressing the challenges and opportunities of soybean cultivation, the ridge and furrow planting system, has garnered attention as an adaptive approach to optimize resource utilization and bolster crop productivity, (Rajput *et al.*, 2009; Negi, 2017). The ridge and furrow system, offers structural advantages in water retention, water distribution, efficient water management (Nagavallemma *et al.*, 2005) and root exploration. The comprehensive methodological framework therefore augments growth and rainfall use efficiency (Ram *et al.*, 2012).

Proper adjustment of spacing helps in maintaining optimum plant population which enables the plants to utilize the land, light, water, nutrients and other input resources more efficiently. The ideal spacing guarantees an optimal leaf area index (Andrade and Abbate 2005) thus ensuring appropriate development of both the aboveground and belowground components of the plant (Malek *et al.*, 2012). Intense spacing, that is reducing the conventional spacing between crop plants, is a non-monetary factor for enhanced growth (Walker and Buchanan 1982) and soybean in intense spacing perform better as compared to widely planted crop (Liebert and Ryan 2017).

Varieties respond in a different way to agronomic manipulations depending upon the microclimate and location of the field. Differential behavior in the growth habit of soybean varieties is attributed to their genetic makeup (Singh *et al.,* 2013). The optimum plant spacing for higher yield may differ according to cultivar and location and therefore specific plant to plant distance needs to be investigated for varieties and agro-climatic conditions of different regions. The interaction between intense spacing and the ridge and furrow planting system in soybean cultivation holds the potential to improve growth patterns, water-use efficiency and economic gains. Intense spacing harnesses the intrinsic relationship between plant density and resource allocation, influencing physiological dynamics critical to crop development. The combination of these two approaches is positioned to reveal new understandings about the growth, Rainfall Use Efficiency (RUE) and economic results in soybean cultivation.

This research endeavors to unravel the multifaceted implications of intense spacing under ridge and furrow planting system on soybean growth, RUE, and economic viability in the *Tarai* region of the Western Himalayas.

MATERIALS AND METHODS

A. Experimental site

The field experiment was conducted at research site of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar-263 145 (Uttarakhand), India during *kharif* growing seasons of 2019-20. The previous crop grown in the experimental field was wheat. pH of the experimental site was 6.8 with 1.18% Organic Carbon, 230 kg/ha available Nitrogen, 22.5 kg/ha available P_2O_5 and132 kg/ha available K_2O.

B. Experimental details

The experiment consisted of 8 treatments and was laid out in split plot design with 3 replications. Main plot treatments were two varieties, PS-1092 and SL-958. Sub plot treatments were four plant to plant spacing (5 cm, 10 cm, 15cm, and 20 cm). Ridge and furrows were made in the field manually at a spacing of 45 cm and height of ridges was 15 cm. The seeds were treated with Thiram 75% WP @ 2g + Bavistine (Carbendazim 50% WP) @ 1.0 g/kg seed and thereafter inoculated with *Bradyrhizobium japonicum* culture @ 500 g per 75 kg seed. After opening of furrows up to a depth of 5 cm in the ridges, sowing was done. 10 days after sowing thinning was done to maintain treatment wise plant density. Treatment wise intra plant spacing was ensured in each plot.

C. Observation and Analysis

Accounts of weather parameters including temperature range, relative humidity and rainfall during the growth period of the crop were obtained from the meteorological observatory located at N. E. Borlaug Crop Research Centre, Pantnagar and are depicted in Fig. 1. Five plants were tagged in the third row for measuring height at 30, 45 and 60 DAS. Plant height was measured from base of the plant to tip of the upper most leaf. For dry matter accumulation, five non tagged representative plants were cut at the base from the sampling row of each plot at 60, 75 and 90 DAS and dried in oven at 65±2°C, till samples attained a constant weight. The weight was measured and divided by five, to obtain dry matter accumulation per plant. The traditional methods were followed for growth analysis (Watson, 1952). Mean values of RGR and CGR were calculated using formulae as those listed by Radford (1967).

Economic analysis is an essential factor in evaluating the results and feasibility of any agronomic experiment. To determine economic feasibility, the cost of cultivating per unit area (Rs. /ha), gross returns, net returns per unit area (Rs. /ha) and Benefit cost ratio was calculated. To calculate the gross return from the produce, the minimum support price of soybean set by the Government of India (Ministry of Agriculture and Farmers Welfare, 2020) was multiplied with the yield of soybean seeds in per hectare basis. To determine the net returns, we subtracted the cost of cultivation for each treatment from their respective gross returns. The statistical analysis of data on various parameters was done by using split plot design described by Gomez and Gomez (1984) with the help of standard approach of Analysis of Variance (ANOVA) using OPSTAT. The critical difference was also calculated to test the significance of difference between two treatments if F test was found significant at 5 % level of significance.

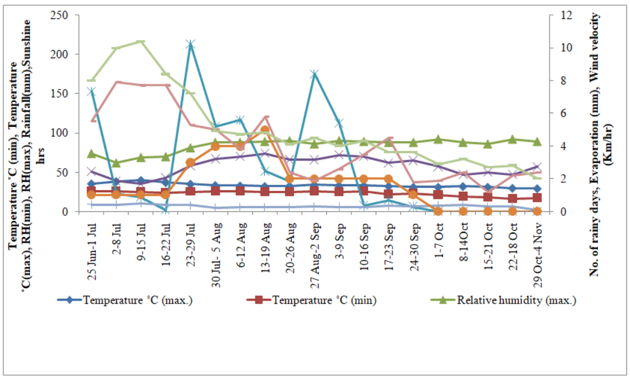

Fig. 1. Weekly weather data of *Kharif* crop season 2019 at G.B. Pant University of Agriculture and Technology.

RESULTS AND DISCUSSION

A. Plant height

The data on plant height computed for different treatments are presented in Table 1. Genotype of the plant significantly affected the plant height at all growth stages as depicted in Fig. 2. The plants of Variety SL 958 was taller than PS 1092 at all observational growth stages, viz., 30 DAS, 45 DAS and 60 DAS. Spacing influenced plant height significantly at 30 DAS and 45 DAS. It was observed that at all growth stages, intense plant to plant spacing of 5 cm, resulted into the tallest plants and with further increase in plant to plant spacing, plant height decreased (Fig. 3). Height of soybean plants grown at plant to plant spacing of 5 cm was the maximum, followed by 10 cm, 15 cm and minimum in 20 cm. As intra row spacing becomes wider, plant height decreased significantly. This was probably due to increased crop competitiveness and rapid canopy closure occurs at narrow spacing (Dalley *et al.*, 2004).

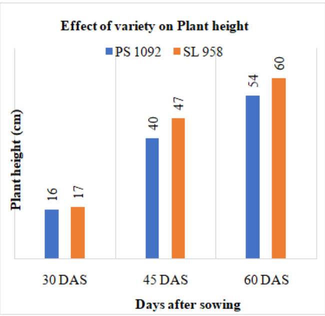

Fig. 2. Plant height (cm) of soybean as influenced by varieties at 30, 45 and 60 DAS.

Due to the higher population density at closer spacing, soybean planted in narrow spacing have higher canopy closure with better canopy cover percentage compared to wide spacing (Daramola *et al.*, 2019). Better canopy coverage at intense spacing as compared to wide spacing, cause mutual shading of leaves that contributes to increased competition for light and therefore results in stem elongation. Elongated stem which may be due to increase in node number or increase in inter-nodal length or both eventually leads to increased plant height (Ahmed *et al.*, 2018). This argument was supported by the statement of Hassan (2015); Çalişkan *et al.* (2015); De Bruin and Pedersen (2008); Cox and Cherney (2011); Akond *et al.* (2013); Chauhan and Opena (2013); Ohyama *et al.* (2013); Gurmu *et al.* (2022); Worku and Astatkie (2011); Gulluoglu *et al.* (2017).

Iyorkaa *et al.* (2021); Jańczak-Pieniążek *et al.* (2021); Bishnoi *et al.* (2021) mentioned that plant height of soybean plants increased with the decrease in spacing because of competition for light. Abeje *et al.* (2020) in their experiment also reported that the longest soybean plant was measured with the narrowed (5 cm) intra row spacing, while the shortest plant was measured with the wider (15 cm) intra row spacing.

At 60 DAS, there was non-significant difference found in plant height at different spacing, which indicates that at later stages of development spacing has no or minimal effect on plant height.

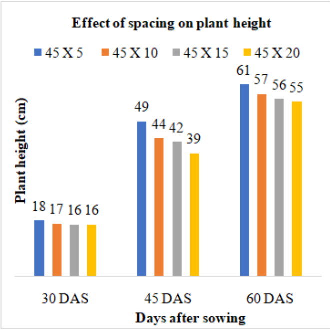

Fig. 3. Plant height (cm) of soybean as influenced by spacing at 30, 45 and 60 DAS.

B. Dry matter accumulation

The data pertaining to dry matter accumulation at various stages of crop growth is presented in Table 2. Varieties influenced dry matter accumulation significantly at 60 DAS but non-significant differences were recorded at 75 DAS and 90 DAS (Fig. 4). At 60 DAS, SL 958 recorded higher dry matter accumulation per plant as compared to PS 1092. At later stages i.e., 75 DAS and 90DAS, variety SL 958 recorded higher dry matter content per plant than variety PS 1092, but the differences between the two were not statistically significant.

In general, as the crop advances in its stage the dry matter content in plant increases and reaches its maximum at maturity (Açikgöz *et al.*, 2013). At 60 DAS and 75 DAS, dry matter accumulation per plant was significantly affected by intra plant spacing. The highest dry matter accumulation was recorded for the widest spacing of 45 cm x 20 cm which decreased significantly, with the decrease in intra plant spacing (Fig. 5), as was also reported by Verma *et al.* (2020). Kuntyastuti *et al.* (2018) also observed that the dry matter accumulation per plant was highest at wider spacing and least in narrow spacing. This can be attributed to the fact that at larger spacing, without any competition, plants get wide open space to grow. This leads to increased number of branches, pods and leaves per plant at wider spacing contributing to increased dry matter production per plant. At 90 DAS, the dry matter accumulation per plant was not affected by change in plant to plant spacing.

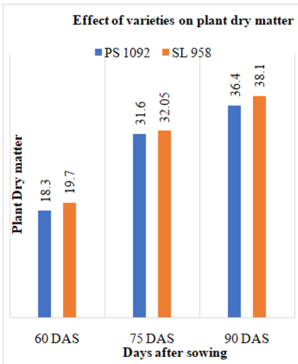

Fig. 4. Dry matter accumulation (g/plant) of soybean as influenced by different spacing.

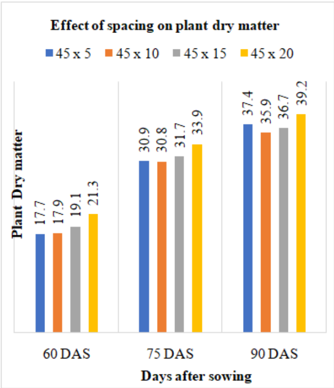

Fig. 5. Dry matter accumulation (g/plant) of soybean as influenced by varieties.

C. Crop growth rate and Relative growth rate

The data presented on Crop Growth Rate (CGR) and Relative Growth Rate (RGR) of crop as influenced by different treatments is presented in Table 2. CGR at 60-75 DAS and 75-90 DAS was not influenced significantly by varieties. Effect of spacing on CGR at both the stages (60-75 DAS and 75-90) DAS was non-significant. At both the stages, higher CGR was recorded for closer spacing of 5 cm (Fig. 6), which might be due to more interception of light in closer spacing and more number of plants per unit area.

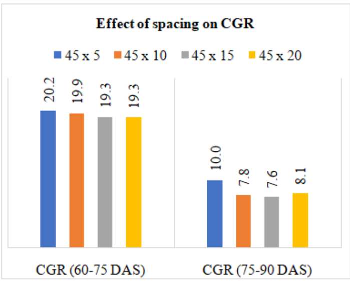

Fig. 6. CGR of soybean as influenced by different spacing.

Similar results were reported by Daroish *et al.* (2005); Kandil *et al.* (2013); Ebrahimi *et al.* (2012); Aastha and Singh (2016). The drastic decrease in CGR from 60-75 DAS to 75-90 DAS is due to leaf abscission starting after the seed filling period and is also related to the fact that much of total dry matter accumulation after 60 DAS is into seed weight which has a much higher energy cost for its manufacture compared with other plant parts Kahlon *et al.* (2018).

RGR at 60-75 DAS and 75-90 DAS was non-significantly influenced by varieties. In general, at vegetative stage of the crop RGR increased with the advancement of time and as the age advances RGR decreases (Fig. 7) due to decrease in photosynthetic area. In this experiment, effect of spacing on RGR at both the stages was not significant as was also reported by Aastha and Singh (2016); Daramola *et al.* (2019).

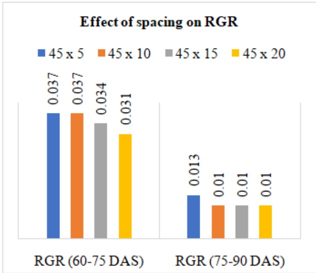

Fig. 7. RGR of soybean as influenced by different spacing.

D. Rainfall use efficiency

The data on rainfall use efficiency of crop as influenced by different treatments are presented in Table 2. Rainfall use efficiency was not significantly different for the two varieties but was significantly affected by different pant to plant spacing. 10 cm plant to plant spacing recorded the maximum RUE, followed by 5 cm spacing. Minimum RUE was recorded from 20 cm plant to plant spacing (1.09Kg/ha/mm) which was significantly lesser than 15 cm. Findings on rainfall use efficiency (RUE) and the impact of different treatments provide valuable insights into the relationship between soybean cultivation practices and water utilization. The variations observed in RUE can be attributed to several factors, both biological and environmental. The higher RUE observed with tighter plant spacing (10 cm) compared to wider spacing (20 cm) could be attributed to the fact that closer spacing allows for better resource utilization by plant population as whole, leading to improved water-use efficiency. Plant spacing can influence the canopy architecture and light interception. The closer spacing (10 cm) may result in a denser canopy, which in turn maximizes light interception (Daramola *et al.*, 2019) and photosynthesis. This efficient use of light may have contributed to better RUE. Closer spacing can create a more favorable microclimate within the canopy, with reduced evaporation and better moisture retention in the soil. This microclimatic effect could contribute to higher RUE.

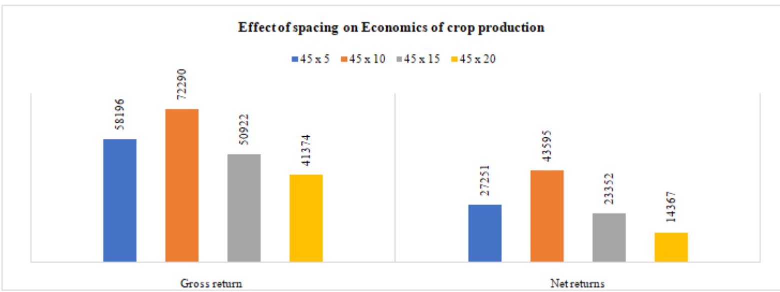

Fig. 8. Economics of soybean as influenced by different treatments.

E. Economic Analysis

The economic analysis presented in Table 3 delves into the financial dimensions of cultivation of soybean varieties in different spacing. This analysis, considering gross return, cost of cultivation, net returns, and the benefit-cost ratio (B: C ratio), offers valuable insights into the economic viability of different treatments, encompassing varietal diversity and spacing arrangements. The varietal choices of PS 1092 and SL 958 exhibit nuanced differences in economic outcomes. Both varieties generate similar gross returns, with PS 1092 at Rs. 55,923 and SL 958 at Rs. 55,468. PS 1092 emerges with a slightly higher net return of Rs. 27,369 and a marginally superior B: C ratio of 0.95 compared to SL 958's net return of Rs. 26,914 and B: C ratio of 0.93. However, the differences between net returns and B: C ratio of varieties was not statistically significant. PS 1092 offers similar economic return in terms of net profit and cost-benefit ratio. This suggests that PS 1092 and SL 958 are economically at par with each other under the given conditions, considering both production costs and revenue generation.

The influence of spacing arrangements on soybean cultivation economics is statistically significantly. Among the spacing treatments, 45 × 10 stands out with the highest gross return of Rs. 72,290. This spacing configuration also demonstrates substantially highest net returns of Rs. 43,595 and the only one with profitable B: C ratio of 1.51, signifying its superiority over the other spacing alternatives. On the other hand, the 45 × 20 spacing arrangement yields comparatively lowest gross and net returns, as well as a significantly reduced B: C ratio of 0.53. The result of benefit cost ratio also showed economic benefit when soybean was planted at narrow row spacing. The result agrees with the report of Iyorkaa *et al.* (2021); Bell *et al.* (2015). The findings suggest that for variety PS 1092 and SL 958, the 45 × 10 spacing arrangement hold promising economic potential for soybean cultivation in the *Tarai* region. Sowing at narrow spacing was economically profitable which was also reported by Schmitz *et al.* (2020); Thompson *et al.* (2015). On the other hand De Bruin and Pedersen (2008) reported that, changes in seeding rates could not lead to changes in profitability.

Table 1: Plant height (cm) and Dry Matter Accumulation (g/plant) of soybean as influenced by different treatments.

Treatments	Plant Height (cm)			Dry Matter Accumulation (g/plant)		
	30 DAS	45 DAS	60 DAS	60 DAS	75 DAS	90 DAS
Varieties						
PS 1092	16	40	54	18.3	31.6	36.4
SL 958	17	47	60	19.7	32	38.1
SEm ±	0.07	1.04	0.33	0.1	0.5	0.7
CD at 5%	0.51	6.82	1.01	1.2	NS	NS
Spacing (cm)						
45 × 5	18	49	60	17.7	30.9	37.4
45 × 10	17	43	57	17.9	30.8	35.9
45 × 15	16	42	56	19.1	31.7	36.7
45 × 20	16	39	55	21.3	33.9	39.1
SEm ±	0.22	1.96	0.5	0.5	0.6	0.8
CD at 5%	0.70	6.12	NS	1.6	1.9	NS

Table 2: CGR, RGR and RUE of soybean as influenced by different treatments.

Treatments	CGR (g/day/m^2)		RGR (g/day/m^2)		Rainfall Use Efficiency (Kg/ha/mm)
	60-75 DAS	75-90 DAS	60-75 DAS	75-90 DAS	
Varieties					
PS 1092	20.47	7.33	0.04	0.01	1.48
SL 958	18.91	9.42	0.03	0.01	1.47
SEm ±	0.88	1.09	0.00	0.00	0.07
CD at 5%	NS	NS	NS	NS	NS
Spacing (cm)					
45 × 5	20.22	10.04	0.04	0.01	1.54
45 × 10	19.88	7.80	0.04	0.01	1.91
45 × 15	19.35	7.56	0.03	0.01	1.35
45 × 20	19.32	8.10	0.03	0.01	1.098
SEm ±	1.35	1.09	0.001	0.001	0.069
CD at 5%	NS	NS	NS	NS	0.216

Table 3: Economics of soybean cultivation (Rs/ha) as influenced by different treatments.

Treatments	Gross returns (Rs)	Cost of cultivation (Rs)	Net returns (Rs)	B:C ratio
Variety				
PS 1092	55923	28554	27369	0.95
SL 958	55468	28554	26914	0.93
SEm ±	1956	-	1956	0.07
CD at 5%	NS	-	NS	NS
Spacing				
45 × 5	58196	30945	27251	0.88
45 × 10	72290	28695	43595	1.51
45 × 15	50922	27570	23351	0.84
45 × 20	41374	27008	14366	0.53
SEm ±	2767.0	-	2766.9	0.10
CD at 5%	8392.6	-	8392.5	0.30

CONCLUSIONS

The findings of the study investigate plant height, dry matter accumulation, crop growth rates, and relative growth rates of varieties in spacing arrangements. Intense spacing's influence on plant height was consistent with the competition for light theory, leading to taller plants at closer intervals. Additionally, the analysis of rainfall use efficiency highlighted the pivotal role of spacing in maximizing water utilization, with tighter spacing promoting superior water-use efficiency. Economically, our analysis underscores the significance of spacing arrangements. The 45 × 10 spacing configuration emerged as the most economically promising, yielding substantial gross and net returns along with a benefit-cost ratio that is more than one. Furthermore, our comparison of PS 1092 and SL 958 varieties revealed nuanced economic outcomes, suggesting comparable economic viability under different conditions. In conclusion, this study points out that amalgamation of intense spacing and the ridge and furrow planting system offers a transformative avenue to advance soybean cultivation in *Tarai* region of western Himalayas. The investigation into the growth, RUE and economics of soybean varieties as influenced by intense spacing under the ridge and furrow planting system in the *Tarai* region of the Western Himalayas embodies a significant step toward unlocking the region's agricultural potential. This research seeks to inform decision-makers, farmers, and researchers, offering evidence-based insights to optimize soybean cultivation practices and foster sustainable agricultural practices.

FUTURE SCOPE

Long term impact of the intense spacing in ridge and furrow planting system on growth of Soybean still needs to investigated. Examining the benefits of intense spacing of soybean in intercropping in *Tarai* area of western Himalayas is a potential area for future research. Investigating how the intense spacing contribute to climate resilience, especially in the face of changing weather patterns and increased climate variability is a novel aspect that demands attention.

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Conflict of Interest. None.

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