Original Research Article

System intensification in ridges and furrow planting to enhance nutrient uptake efficiency in Soybean

ABSTRACT

AIMS: Through the study we aim to explore agronomic intervention to provide nutritional security to growing population, with limited resources and changing climatic conditions. The objective of the study is to investigate the impact of system intensification on nutrient content and nutrient uptake in soybean varieties within ridge and furrow planting system. The study also compares the nutrient use efficiency of different spacing treatments in soybean.

Study design: The experiment was designed in a split-plot layout with eight treatments, replicated three. The main plot treatments included two soybean varieties: PS-1092 and SL-958. Four system intensification treatments were within the sub-plots, (plant-to-plant spacing -5 cm, 10 cm, 15 cm, and 20 cm).

Place and Duration of Study: The experiment was conducted during *Kharif* growing season of 2019 at Pantnagar, India.

Methodology: The experiment was laid out in split plot design within ridge configuration, which was manually established in the field. The spacing according to the treatment specifications was maintained 10 days after sowing, through thinning. The seeds and stover samples collected were dried, ground and analyzed chemically for the primary macronutrients and sulfur.

Results: Nitrogen, Phosphorus, Potassium and Sulfur content in seed was significantly highest at spacing 10 cm as compared to other spacing treatments (*P value=.05*). Nitrogen, Phosphorus Potassium and Sulfur uptake for both seed and stover was the maximum at plant to plant spacing of 10 cm which was significantly higher than other plant to plant spacing treatments at 5 % level of significance. Intense plant to plant spacing of 10 cm resulted into the significantly higher partial factor productivity (PFP) of nutrients at *P=.05*. Wider spacing resulted into increased internal efficiency and nutrient harvest index as compared to narrow spacing treatments.

Conclusion: Although nutrient content and uptake in soybean is higher at plant to plant spacing of 10 cm, nutrient use efficiency is better achieved at wider spacing. Under no fertilizer limitation, system intensification can be useful to enhance nutrient content of seeds but in cases of limited fertilizer availability wider spacing is more beneficial to achieve higher nutrient use efficiency. By optimizing the soybean spacing for higher nutrient efficacy, the study paves the way to fortify soybean with limited resources and without genetic manipulation but further investigations are needed to fine-tune these practices across diverse geographic regions and soil types. GHG emissions and cradle to grave carbon foot print of soybean grown in varying planting geometry needs to be studied for aligning agricultural practices with Sustainable Development Goals of United Nations Development Program.

Keywords: Internal efficiency, Nutrient content, Partial factor productivity, Uptake

1. INTRODUCTION

Providing nutritional security to ever growing population, with limited resources and changing climatic conditions is a major challenge [1]. Soybean, a legume crop with a global production of 391.17 million metric tons, and high nutrient status (nitrogen, sulfur, protein and oil content of 6.6, 0.25, 15–22, and 36–45, respectively), holds the potential to resolve the problem of malnutrition in developing and underdeveloped nations [2-4]. Soybean exhibits remarkable variations in response to agronomic modifications. Therefore, agronomic management in soybean could be modified to achieve higher nutrient uptake and better nutrient use efficiency. System intensification is one such agronomic manipulation that could emerge as an important focus for improving nutrient content in soybean [5].

System intensification attempts to increase light penetration through improved crop canopy coverage while minimizing interspecific competition by limiting weed growth [6- 8]. As a result, soybean planted at closer spacing performs better than crop sown at broader spacing [9, 10]. However, due to intensive intraspecific competition for resources and inputs, plants grown with very close spacing see a reduction in nutrient content and uptake [10]. Therefore, for obtaining maximum nutrient content and uptake in soybeans, the determination of optimum spacing under system intensification is necessary.

Understanding the benefits of system intensification on nutrient content and nutrient uptake in ridge and furrow planting could help in achieving higher nutrient use efficiency in a sustainable and resource-efficient manner. Soybean sowing in ridge and furrow planting systems enhances crop performance, particularly in areas prone to waterlogging or excessive rainfall. This system offers improved drainage and reduced waterlogging, thereby creating an environment conducive to root growth, nodule formation, and nutrient uptake [12]. Considering these points, the research was planned to investigate the impact of system intensification on nutrient content and nutrient uptake in various soybean varieties within the ridge and furrow planting systems. By systematically evaluating how intensification in soybeans influences nutrient acquisition and utilization, this study aims to investigate the effects of intense spacing within the ridge and furrow planting systems on nutrient content and nutrient uptake in different soybean varieties.

2. MATERIAL AND METHODS

2.1 Experimental site

The experiment was conducted at E3 block of Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology in Pantnagar, India. University is situated at an elevation of 243.8 meters above mean sea level, with geographical coordinates of 29° N latitude and 79.5° E longitude and represents the highly fertile *Tarai* area of western Himalayas. The soil of the experimental site is Typic hapludoll with the characteristics described in Table 1. Pantnagar falls under a sub-humid, sub-tropical climatic regime where summers are very hot and dry and winters are chilling cold with the common phenomenon of occurrence of frost in the months of January and February. The mean weekly minimum temperature ranged from 25.4ºC in June to 18.5ºC in October whereas the mean weekly maximum temperature ranged from 37.2º C in June to 32.6º C in October. The maximum relative humidity ranged from 76 to 93% and minimum ranged from 44 to 84 % during crop period. The rainfall was continuous and was sufficient for the growth of crop thus no irrigation was applied to the crop.

Table 1: Characteristics of soil sample taken from experimental site (0 to 15 cm).

S. No.	Particulars	Values	Method
1	pH	6.8	Blackman glass electrode pH meter method [13]
2	Organic Carbon	1.18%	Walkley and Black [14]
3	Available Nitrogen (kg/ha)	230 kg/ha	Alkaline potassium permanganate method [15]
4	Available P_2O_5 (kg/ha)	22.5 kg/ha	Olsen’s method [16]
5	Available K_2O (kg/ha)	132 kg/ha	Flame photometer [13]
6	Available Sulphur (Kg/ha)	21.8 kg/ha	0.01 M $CaCl_2$ [17]

2.2 Study design and treatment details

The experimental design comprised eight treatments, arranged in a split-plot layout with three replications. The main plot treatments included two soybean varieties: SL-958 and PS-1092. SL 958, a variety released from Punjab Agriculture University, is resistant to yellow mosaic and soybean mosaic viruses. SL 958 was developed by Gill et al. using a pedigree approach from cross of two yellow mosaic-resistant cultivars, i.e. SL 525× SL 706. The variety has characteristic white flowers, matures in about 139 days and produces about 7.3 quintals of seeds per acre on average. It has been released for general cultivation in Punjab and identified for Northern Plain Zone during 2014 [18]. Second variety PS 1092 is a rust and rhizoctonia aerial blight tolerant and is resistant to bacterial pustule, cercospora leaf spot and yellow mosaic virus. The variety has purple flowers and matures in

118-120 days. It is recommended for tarai and bhabar region of UP and tarai and bhabar to mid hills of Uttarakhand [19]. System intensification treatments were within the sub-plots, with four plant-to-plant spacings (5 cm, 10 cm, 15 cm, and 20 cm). Ridge and furrow planting beds were manually established in the field, spaced 45 cm apart, with ridge heights set at 15 cm. Soybean seeds were subjected to treatment with Thiram 75% WP at a rate of 2g per kg of seed, combined with Bavistine (Carbendazim 50% WP) at 1.0 g/kg seed. Subsequently, the seeds were inoculated with *Bradyrhizobium japonicum* culture at a rate of 500 g per 75 kg of seed. Sowing occurred once furrows were opened to a depth of 5 cm within the ridges. After emergence (10 days after sowing), spacing was adjusted through thinning to maintain the desired treatment specifications.

2.3 Nutrient content

From each experimental plot, representative samples of both seeds and stover were collected at harvest. The seeds and stover were dried at 60 °C in a hot air oven and subsequently ground using a Wiley mill to pass through a 1 mm screen. Chemical analysis of the primary macronutrients and sulfur content within seeds and stover was conducted in accordance with established methods. Nitrogen estimation in plant sample was done by H2SO4 digestion followed by micro Kjeldahl distillation method [20]. Phosphorus content and potassium content in plant was estimated by diacid digestion followed by spectrophotometric determination and flame photometric determination, respectively [21]. Sulfur content was determined turbidimetrically as $BaSO_4$ by a barium chloride-gelatin procedure [22].

2.4 Nutrient uptake

Nutrient uptake in seeds was determined using nutrient content in the seed and total seed yield. Likewise, nutrient uptake in the stove was calculated using the nutrient content in the stove and the total stover yield. Nutrient uptake in seeds and stover was added to calculate the total nutrient uptake by the soybean crop. To determine nutrient uptake, the following formula was employed:

Nutrient uptake by seeds (kg/ha) = Nutrient content in seeds (%) × Seed yield (kg/ha) / 100

Nutrient uptake by stover (kg/ha) = Nutrient content in stover (%) × stover yield (kg/ha) / 100

Total nutrient uptake = Nutrient uptake by seeds + nutrient uptake by stover

2.5 Nutrient use efficiency

Nutrient use efficiency for N, P, and K was expressed in terms of partial factor productivity (PFP) and internal efficiency (IE).The following formulas were used for the determination of nutrient use efficiency [23]: -

$$\text{Partial factor productivity} \quad = \frac{\text{Grain yield (kg/ha)}}{\text{Amount of Nutrient applied (kg/ha)}}$$

$$\text{Internal efficiency} \quad = \frac{\text{Grain yield (kg/ha)}}{\text{Total Nutrient uptake by plant (kg/ha)}}$$

2.6 Nutrient harvest index

The nutrient harvest index (NHI) is a ratio that compares the amount of nutrients in the grain to the amount of nutrients in the grain and straw. The NHI is calculated by dividing the nutrient removed by the nutrient uptake and multiplying by 100 to get a percentage. The NHI is an important index to measure retranslocation efficiency of absorbed nutrient from vegetative plant parts to grain. This index is very useful in measuring nutrient partitioning in crop plants, which provides an indication of how efficiently the plant utilized acquired nutrient for grain production [24].

$$\text{Nutrient harvest index} = \frac{\text{Nutrient uptake in Grain (kg/ha)}}{\text{Total Nutrient uptake by plant (kg/ha)}}$$

2.6 Statistical Analysis

Data for various parameters was analyzed for variance at the 5% level of significance using Fischer's method of analysis of variance. Significant treatment differences were evaluated using the value of critical difference. Statistical analysis of all parameters was carried out utilizing the split-plot design methodology as described by Gomez and Gomez [25] with the help of OPSTAT software [26].

3. RESULTS AND DISCUSSION

3.1 Nutrient content

Seeds of variety SL 958 had statistically the same N, P, and S content as seeds of PS 1092. The N, K, and S content in the stover were also statistically same in both varieties. Significantly higher K content in the seeds of SL 958 was recorded (1.63%) in comparison to PS 1092 (*P value* =.00151). P% was higher in the stover of SL 958 than PS 1092. The effect of system intensification had significant impact on the nutrient content of seed and stover(*P value* =.05). N, P, and S content in seed and stover was the maximum when sown at a plant-to-plant spacing of 10 cm. Higher P content observed in soybean seeds at narrow spacing is also confirmed by previous studies [27]. The increased P uptake at intense spacing may be due to the higher N content at narrow spacing and the synergistic effect between N and P. The increased N content at narrow spacing favors greater mobilization of phosphorus in the presence of nitrogen [28]. Potassium content in soybean seeds was the maximum at 20 cm plant-to-plant spacing (1.61%). In the stover, the highest potassium content was observed at a spacing of 15 cm.

3.2 Nutrient uptake

The nutrient uptake in seeds and stover of the two varieties was almost the same except for potassium. K uptake in the seeds of SL 958 was significantly higher than that of PS 1092. No significant difference was recorded between varieties SL 958 and PS 1092 for total N, P, K, and S uptake. N, P, K, and S uptake for both seed and stover was significantly influenced by intensification treatments and was at its maximum at a plant-to-plant spacing of 10 cm (Table 3). Increased aboveground plant accumulation of N, P, K, and S at higher seed rates or at wide spacing has already been reported [29]. However, they concluded that grain accumulation of N, P, K, and S was not influenced by seed rate or spacing. A three year study suggested that the maximum total uptake of nutrients in soybean is under higher seed rate i.e., intense spacing [30].

Treatments	**N % in seed**	**P % in seed**	**K % in seed**	**S % in seed**	**N % in stover**	**P % in stover**	**K % in stover**	**S % in stover**
Variety								
PS 1092	6.3 ±0.030	0.60 ±0.009	1.36 ±0.08	0.29 ±0.011	1.52 ±0.036	0.33 ±0.005	0.73 ± 0.054	0.14 ± 0.007
SL 958	6.43 ±0.030	0.64±0.009	1.63±0.08	0.32±0.011	1.65±0.036	0.37 ±0.005	0.83 ± 0.054	0.15 ± 0.007
P Value	.09435	.10476	.00151	.163	.118	.026	.306	.191
CD (*p* = 0.05)	N/A	N/A	0.050	N/A	N/A	.031	N/A	N/A
Spacing								
45 x 5	6.2 ±0.049	0.61 ±.006	1.35 ±0.061	0.27 ±0.011	1.48 ±0.062	0.34 ± 0.008	0.69 ±.054	0.15 ± 0.007
45 x 10	6.6±0.049	0.65 ±.006	1.45±0.061	0.36 ±0.011	1.90 ±0.062	0.37 ± 0.008	0.76 ±.054	0.17 ± 0.007
45 x 15	6.3±0.049	0.62 ±.006	1.57±0.061	0.27 ±0.011	1.38 ±0.062	0.34 ± 0.008	0.85 ±.054	0.13 ± 0.007
45 x 20	6.3±0.049	0.60 ±.006	1.61±0.061	0.34±0.011	1.57±0.062	0.34± 0.008	0.81 ±.054	0.13 ± 0.007
P Value	.00029	.0003	.04190	.00012	.00043	.043	.246	.0023
CD (*p* = 0.05)	0.154	0.019	0.189	.036	0.193	0.026	N/A	0.023

Table 2: Nutrient content in soybean as influenced by different treatments

Treatments	N uptake in seed (kg/ha)	N uptake in stover (kg/ha)	Total N uptake (kg/ha)	P uptake in seed (kg/ha)	P uptake in stover (kg/ha)	Total P uptake (kg/ha)	K uptake in seed (kg/ha)	K in stover (kg/ha)	Total K uptake (kg/ha)	S uptake in seed (kg/ha)	S in stover (kg/ha)	Total S uptake (kg/ha)
Variety												
PS 1092	95.4 ± 4.59	51.6 ± 4.536	147.1 ±9.049	9.2 ±0.375	11.0 ±.738	20.2±1.107	20.754±0.461	24.8±2.663	45.6±3.064	4.4 ±0.299	4.7 ±.159	9.0 ±0.452
SL 958	96.9 ± 4.59	55.4± 4.536	152.3±9.049	9.6 ±0.375	12.2 ±.738	21.8±1.107	24.8±0.461	26.3±2.663	51.1±3.064	4.9±0.299	5.1 ±.159	10.0±0.452
P value	.8439	.6178	.72448	.51751	.38580	.42382	.025	.73599	.33318	.32750	.18218	.25883
CD (*P* = 0.05)	N/A	N/A	N/A	N/A	N/A	N/A	3.022	N/A	N/A	N/A	N/A	1.6
Spacing												
45 x 5	97.7±4.558	55.5 ± 4.464	153.3 ± 8.356	9.6 ±0.489	12.7±0.765	22.3±1.075	21.9 ±1.223	25.9±2.035	47.8±2.513	4.2 ±0.263	5.6 ±.353	9.8 ±0.502
45 x 10	129.7±4.558	81.3 ± 4.464	211.1± 8.356	12.7±0.489	15.8±0.765	28.6±1.075	34.5±1.223	40.7±2.035	75.2±2.513	7.0±0.263	7.3±.353	14.3±0.502
45 x 15	86.6 ± 4.558	40.9 ± 4.464	127.5± 8.356	8.6±0.489	10.0±0.765	18.5±1.075	19.3±1.223	19.8±2.035	39.1±2.513	3.6±0.263	3.7±.353	7.3±0.502
45 x 20	70.6± 4.558	36.3 ± 4.464	106.9± 8.356	6.7±0.489	7.9±0.765	14.6±1.075	15.3±1.223	15.9±2.035	31.2±2.513	3.8±0.263	2.9±.353	6.7±0.502
P value	.00001	.00005	.00001	.00001	.00005	.00001	.0000	.00001	.00000	.00000	.00001	.0000
CD (*P* = 0.05)	14.200	13.908	26.032	1.525	2.385	3.350	3.811	6.339	7.829	0.819	1.101	1.564

Table 3: Nutrient uptake in soybean as influenced by different treatments

3.3 Nutrient Use Efficiency

3.3.1 Partial factor productivity

Varieties had no influence on the partial factor productivity of nutrients (N, P, K, and S). Spacing treatments showed their effect on the PFP of nutrients at 5 % level of significance. Intense plant-to-plant spacing of 10 cm resulted in the highest PFP of nutrients, which was greater than any other treatment. The widest spacing treatment of 20 cm resulted in the lowest values of PFP.

Treatments	**PFP of N**	**PFP of P**	**PFP of K**	**PFP of S**
Variety				
PS 1092	60.3 ± 2.7	25.1 ± 1.135	37.68382 ±1.702	75.36765 ± 3.405
SL 958	59.8 ± 2.7	24.9183 ± 1.135	37.37745 ±1.702	74.7549 ± 3.405
P Value	.909	.910	.910	.910
CD (P = .05)	N/A	N/A	N/A	N/A
Spacing				
45 X 5	62.7± 2.8	26.14379 ± 1.172	39.21569 ± 1.758	78.43137 ±3.516
45 x 10	77.9 ± 2.8	32.47549 ± 1.172	48.71324 ± 1.758	97.42647 ±3.516
45 x 15	54.9 ± 2.8	22.87582 ± 1.172	34.31373 ± 1.758	68.62745 ±3.516
45 x 20	44.60 ± 2.8	18.5866 ± 1.172	27.8799 ± 1.758	55.7598 ±3.516
P Value	.00002	.00002	.00002	.00002
CD (P = .05)	5.476	3.651	5.476	10.952

Table 4: Partial factor productivity of nutrients in soybean as influenced by different treatment

3.3.2 Internal efficiency of nutrients

Nitrogen internal efficiency (NIE) was not influenced by the genotype but was significantly affected by the spacing at 5 % level of significance. Wider spacing resulted in a higher NIE as compared to narrow spacing. NIE was recorded at its maximum when plant-to-plant spacing was 15 cm, which was 16.6 % higher than the lowest value of NIE obtained at 10 cm. Variety PS 1092 exhibited 3.9% higher phosphorus internal efficiency (PIE) than SL 958 *(P = .207)*. The effect of spacing on PIE was not significant at *P = .05*. Potassium internal efficiency (PoIE) did not show a varietal effect and was not influenced by change in genotype. Intense spacing significantly influenced the PoIE at 5% level of significance. The maximum PoIE was observed for the plant-to-plant spacing of 20 cm. The internal efficiency of sulfur (SIE) was not influenced by the varieties. SIE was higher at wider spacings as compared to narrow spacings. SIE was reported to be the maximum at 15 cm plant-to-plant spacing.

Internal efficiency (Kg yield / Kg nutrient uptake)				
Treatments	**N**	**P**	**K**	**S**
Variety				
PS 1092	10.38404 ± 0.117	73.87922 ± 1.082	32.55763 ± 0.267	169.2251 ± 5.915
SL 958	10.03176 ± 0.117	71.05848 ± 1.082	31.65849 ± 0.267	156.5441 ± 5.915
P Value	.167	.207	.140	.268
CD (P = .05)	N/A	N/A	N/A	N/A
Spacing				
45 X 5	10.24986 ± 0.239	69.07598 ± 2.313	31.73989 ± 1.579	158.4383 ± 7.816
45 x 10	9.268261± 0.239	71.80063 ± 2.313	25.80541 ± 1.579	136.8505 ± 7.816
45 x 15	10.80952 ± 0.239	74.23757 ± 2.313	34.92646 ± 1.579	187.1384 ± 7.816
45 x 20	10.50395 ± 0.239	74.76121 ± 2.313	35.96049 ± 1.579	169.1111 ± 7.816
P Value	.0037	.329	.002	.005
CD (P = .05)	0.744	N/A	4.920	24.352

Table 5: Internal efficiency of nutrients in soybean as influenced by different treatments

3.4 Nutrient Harvest Index

Varieties had no influence on the nutrient harvest index of nitrogen, phosphorus, potassium, and sulfur. The nitrogen harvest index and sulfur harvest index was influenced by spacing treatments at 5 percent level of significance. Wider spacing resulted into higher values of harvest index of nutrients. The higher nitrogen harvest index and sulfur harvest index were observed at wider plant-to-plant spacing. Nitrogen harvest index at 15 cm spacing was the highest which was 10.5% greater than the least value of nitrogen harvest index observed at 10 cm spacing. Range of sulfur harvest index of soybean under different spacing was wider than nitrogen harvest index. Harvest index of sulfur at 20 cm spacing was 29.6% higher than the values observed at 5 cm spacing. The harvest index of phosphorus and potassium was not influenced by plant-to-plant spacing at 5 % level of significance.

Treatments	**N harvest index (%)**	**P harvest index (%)**	**K harvest index (%)**	**S harvest index (%)**
Variety				
PS 1092	65.5323 ± 0.821	46.78429 ± 0.638	48.64514 ±1.445	50.49266 ± 0.622
SL 958	64.4895 ± 0.821	45.49545 ± 0.638	48.64105 ±1.445	48.98014 ± 0.622
P Value	.4634	.2893	.000	.227
CD (*p* = 0.05)	N/A	N/A	9.467	N/A
Spacing				
45 X 5	63.88571 ± 1.352	44.62507 ± 1.435	48.32947 ±1.934	43.96624 ± 2.169
45 x 10	61.599 ± 1.352	45.92049 ± 1.435	46.92913 ±1.934	48.65394 ± 2.169
45 x 15	68.0749 ± 1.352	46.13053 ± 1.435	49.901 ±1.934	49.33848 ± 2.169
45 x 20	66.48399 ± 1.352	47.8834 ± 1.435	49.4128±1.934	56.98695 ± 2.169
P Value	.0251	.48295	.71241	.0087
CD (*p* = 0.05)	4.211	N/A	N/A	6.75

Table 6: Harvest index of nutrients in soybean as influenced by different treatments

4. CONCLUSION

Higher nutrient content and uptake in soybean seeds is achieved by intensified sowing at a plant-to-plant spacing of 10 cm, and nutrient use efficiency is better achieved at wider spacing. Under no fertilizer limitation, system intensification is useful to enhance the nutrient content of seeds but, with limited fertilizer availability, wider spacing is more beneficial to achieve higher nutrient use efficiency.

FUTURE PROSPECTS

By optimizing the soybean spacing for higher nutrient efficacy, the study paves the way for new agronomic approaches to fortify the soybean crop but further investigations are needed to fine-tune these practices across diverse geographic regions and soil types. Research concludes that nutrient harvest index were not influenced by change in genotype, therefore genetic manipulations to enhance translocation of nutrients could be the area of focus. In light of climate variability, investigating resilience of crops nutrient efficiency to changing conditions needs to be studied. Leveraging digital agriculture and engaging policymakers for dissemination can further enhance the impact of this research. Considering environmental implications like GHG emissions and carbon foot print of soybean cultivation in varying planting geometry are vital for sustainable soybean production. This requires requiring interdisciplinary studies on the ecological footprint and international partnerships to share best practices and innovations for “Responsible Consumption and Production”- a Sustainable Development Goal of UNDP [31].

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COMPETING INTERESTS

“Authors have declared that no competing interests exist.”

AUTHORS’ CONTRIBUTIONS

“Pragya Naithani conducted the study, performed the statistical analysis, conducted the literature searches, and wrote the first draft of the manuscript. Dr. Ajay Kumar designed the experiment and managed the analyses of the study. All authors read and approved the final manuscript.”

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