Original Research Article

Enhancing Nutrient Uptake Efficiency in Soybean Varieties through System Intensification in Ridge and Furrow Planting System

ABSTRACT

Aims: To investigate the impact of system intensification on nutrient content and nutrient uptake in various soybean varieties within ridge and furrow planting system. This study aims to investigate the effects of intense spacing within the ridge and furrow planting system on nutrient use efficiency.
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 conducted in ridges, which were 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: N, P and S content in seed and stover was the highest at spacing 10 cm. K content in seeds and stover was higher at 20 cm and 15 cm spacing, respectively. N, P, K and S uptake for both seed and stover was the maximum at plant to plant spacing of 10 cm. Intense plant to plant spacing of 10 cm resulted into the highest PFP of nutrients. Wider spacing resulted into higher 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.

Keywords: Nutrient content, Nutrient uptake, Nutrient harvest index, Nutrient internal efficiency, Partial factor productivity,

1. INTRODUCTION

With the population growing, nutrition security is a global concern. Providing nutritional security with limited resources and changing climatic conditions is a major challenge. Soybean, a legume crop with a global production of 391.17 million metric tons [1], 6.6% nitrogen content, 0.25 percent sulfur content [2], 15–22 percent protein, and 36–45 percent oil content [3] in its seed, holds the potential to provide nutritional security to an ever growing population. As a highly responsive crop, soybean exhibits remarkable variations in response to agronomic modifications. To meet the challenge of nutritional security, agronomic management in soybeans could be modified to attain higher nutrient content and uptake. System intensification is one such agronomic manipulation that could emerge as an important focus for improving nutrient content [4].

System intensification attempts to increase light penetration through improved crop canopy coverage [5] while minimizing interspecific competition by limiting weed growth [6, 7]. As a result, soybean plants planted with closer spacing perform better than plants grown with broader spacing [8, 9]. However, due to intensive intraspecific competition for resources and inputs, plants grown with very close spacing see a reduction in nutrient content

Comment [KK1]: You start writing abstract by briefly introducing the problem of your study then followed by the general obective of the study, methodolgy, results, conclusion and recommendation

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Comment [KK3]: Please clearly indicate the type of study design used whether RCBD or CBD.

Comment [KK4]: Instead of saying highest/higher, why don't you write the significant value observed in the results which is either p≤0.5 or ≥0.5 depending on the agreed level of confidence chosen while running the analysis

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Comment [KK7]: The word nutrient is over being repeated, please re-write. I suggest you nutrient content, uptake, harvest index, internal efficiency

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and uptake [10]. Therefore, for obtaining maximum nutrient content and uptake in soybeans, the determination of optimum spacing under system intensification is necessary.

Soybean sowing in ridge and furrow planting systems can enhance 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 [11].

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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. 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

Study design and treatment

Comment [KK10]: After the experimental site/study area, please write details description on the study design used e.g., RCBD, CBD etc. Please, clearly specify the different varieties of soybeans used in the study and how experimental treatments assigned to each.

Table 1: Characteristics of experimental site.

S. No.	Particulars	Values	Method
1	pH	6.8	Blackman glass electrode pH meter method [12]
2	Organic Carbon	1.18%	Walkley and Black [13]
3	Available Nitrogen (kg/ha)	230 kg/ha	Alkaline potassium permanganate method [14]
4	Available P_2O_5 (kg/ha)	22.5 kg/ha	Olsen's method [15]
5	Available K_2O (kg/ha)	132 kg/ha	Flame photometer [12]
6	Available Sulphur (Kg/ha)	21.8 kg/ha	0.01 M $CaCl_2$ [16]

Table 2: Method of estimation of nutrient in seed and stover samples.

S.No.	Nutrient	Method of estimation
1	Nitrogen content	Snell and Snell [17]
2	Phosphorus content	Jackson [18]
3	Potassium content	Jackson [18]
4	Sulfur content	Tabatabai and Brenner [19]

Comment [KK11]: These details come after study design and treatment; it is highly recommended NOT to present the methods used in a tabular form. Kindly write a brief description of each method, about 3-4 lines before inserting citation

The experiment was conducted during *Kharif* growing season of 2019 as a part of soybean-wheat cropping system at E3 block of Norman E. Borlaug Crop Research Centre, G.B. 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. The soil of the experimental site is Typic hapludoll with the characteristics described in Table 1.

Comment [KK12]: Write all the acronyms used for the first time in full please

Comment [KK13]: Description of the study area should be immediately after the sub-heading experimental site and it should capture details like; the duration of your study, reason for choosing the study site, geographical coordinates of the study site and climate or wheather pattern experience in the study site.

2.2 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: PS-1092 and SL-958. 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.

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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, described in Table 2.

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), internal efficiency (IE), and nutrient harvest index (NHI). The following formulas were used for the determination of nutrient use efficiency [20]: -

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

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

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

Comment [KK15]: This is good, I suggest you be elaborate as this for parameters measured as well.

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 [21] with the help of OPSTAT software.

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3. RESULTS AND DISCUSSION

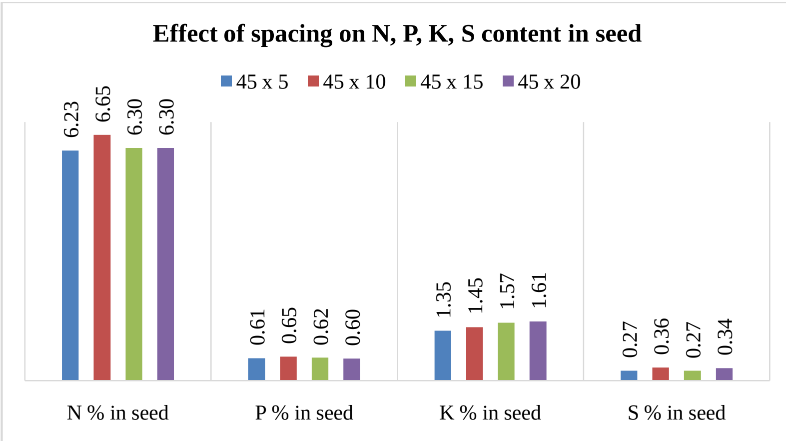

Fig. 1: Nutrient content in seed of soybean as influenced by different spacing treatments

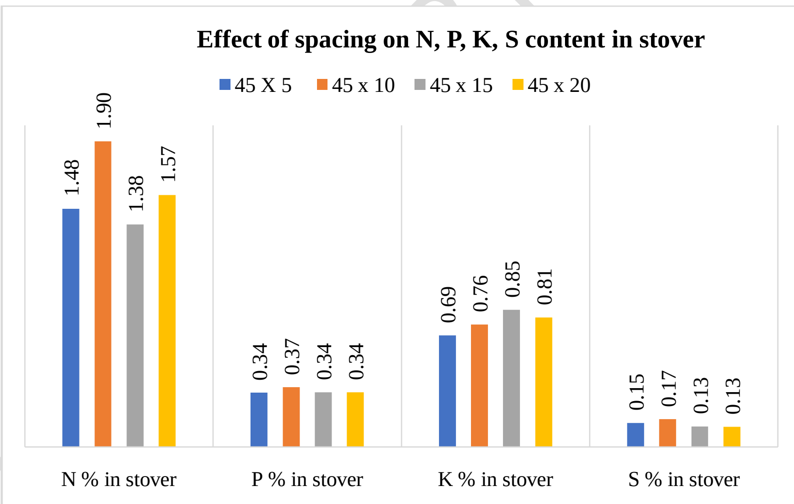

Fig. 2: Nutrient content in stover of soybean as influenced by different treatments

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 was statistically the same in both varieties. Significantly higher K content in the seeds of SL 958 was recorded (1.63%) in comparison to PS 1092. P% was higher in the stover of SL 958 than PS 1092. The effect of system intensification was significant on the nutrient content of seed and stover (Figs. 1 and 2). N, P, and S content in seed and stover was the highest when sown at a plant-to-plant spacing of 10 cm. Moreira et al.

Comment [KK17]: I suggest you present this result in a table form where means, standard deviation and p-value for each parameter will be clearly indicated. And, please read the journal authors' guidelines to understand whether results and discusion should be combined or separated.

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[22] also confirmed that a higher P content is observed in soybean seeds at narrow spacing. 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, as was reported by Hocking and Pinkerton [23]. Potassium content in soybean seeds was significantly higher at 20 cm plant-to-plant spacing (1.61%). In the stover, the highest potassium content was observed at a spacing of 15 cm. Findings of Moreira et al. [22] report no significant effect of spacing on the N, K, and S content of seeds and the N, P, K, and S content of leaves.

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Comment [KK22]: This is a good insight, please think a little harder and write more on that and, your opinion should come immediately after presenting the result since RESULT & DISCUSSION is combined. Thereafter, you start to compare your findings with the existing literature whether your findings concure or disagree withtheir study. Please apply this in all your discussion.

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

	N uptake (kg/ha)			P uptake (kg/ha)			K uptake (kg/ha			S uptake (kg/ha)		
Treatments	**Seed**	**Stover**	**Total**	**Seed**	**Stover**	**Total**	**Seed**	**Stover**	**Total**	**Seed**	**Stover**	**Total**
Variety												
PS 1092	95.4	51.6	147.1	9.2	11.0	20.2	20.8	24.8	45.6	4.4	4.7	9.0
SL 958	96.9	55.4	152.3	9.6	12.2	21.8	24.8	26.3	51.1	4.9	5.1	10.0
SEm ±	4.54	4.53	9.04	0.4	0.7	1.1	0.5	2.7	3.1	0.3	0.2	0.5
CD (*P*=.05)	NS	NS	NS	NS	NS	NS	3.0	NS	NS	NS	NS	NS
Spacing												
45 x 5	97.7	55.5	153.3	9.6	12.7	22.3	21.9	25.9	47.8	4.2	5.6	9.8
45 x 10	129.7	81.3	211.1	12.7	15.8	28.6	34.5	40.7	75.2	7.0	7.3	14.3
45 x 15	86.6	40.9	127.5	8.6	10.0	18.5	19.3	19.8	39.1	3.6	3.7	7.3
45 x 20	70.6	36.3	106.9	6.7	7.9	14.6	15.3	15.9	31.2	3.8	2.9	6.7
SEm ±	4.5	4.4	8.3	0.5	0.8	1.1	1.2	2.0	2.5	0.3	0.4	0.5
CD (*P* =.05)	14.2	13.9	26.0	1.5	2.4	3.4	3.8	6.3	7.8	0.8	1.1	1.6

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). T. Purucker and Steinke [24] reported increased aboveground plant accumulation of N, P, K, and S at higher seed rates or at wide spacing. However, they concluded that grain accumulation of N, P, K, and S was not influenced by seed rate or spacing.

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

Treatments	**PFP of N**	**PFP of P**	**PFP of K**	**PFP of S**
Variety				
PS 1092	60.29412	25.12255	37.68382	75.36765
SL 958	59.80392	24.9183	37.37745	74.7549
SEm ±	2.10943	0.878929	1.318394	2.636788
CD (*P* =.05)	NS	NS	NS	NS
Spacing				
45 X 5	62.7451	26.14379	39.21569	78.43137
45 x 10	77.94118	32.47549	48.71324	97.42647
45 x 15	54.90196	22.87582	34.31373	68.62745
45 x 20	44.60784	18.5866	27.8799	55.7598

SEm ±	2.983185	1.242994	1.864491	3.728981
CD (*P* =.05)	9.04	3.77023183	5.655348	11.3107

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

Internal efficiency (Kg yield / Kg nutrient uptake)				
Treatments	**N**	**P**	**K**	**S**
Variety				
PS 1092	10.38404	73.87922	32.55763	169.2251
SL 958	10.03176	71.05848	31.65849	156.5441
SEm ±	0.162401	1.568539	1.0387	5.584086
CD (*P* =.05)	NS	0.026	NS	NS
Spacing				
45 X 5	10.24986	69.07598	31.73989	158.4383
45 x 10	9.268261	71.80063	25.80541	136.8505
45 x 15	10.80952	74.23757	34.92646	187.1384
45 x 20	10.50395	74.76121	35.96049	169.1111
SEm ±	0.22967	2.218249	1.468943	7.89709
CD (*P* =.05)	0.696631	NS	4.455579	23.95335

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

Treatments	**N harvest index (%)**	**P harvest index (%)**	**K harvest index (%)**	**S harvest index (%)**	***P-value***
Variety					
PS 1092	65.5323±	46.78429±	48.64514±	50.49266±	
SL 958	64.4895	45.49545	48.64105	48.98014	
SEm ±	0.9377	0.9699	1.37	1.43	
CD (*P* =.05)	NS	NS	NS	NS	
Spacing					
45 X 5	63.88571	44.62507	48.32947	43.96624	
45 x 10	61.599	45.92049	46.92913	48.65394	
45 x 15	68.0749	46.13053	49.901	49.33848	
45 x 20	66.48399	47.8834	49.4128	56.98695	
SEm ±	1.3261	1.371664	1.949	2.035	
CD (*P* =.05)	4.0224	NS	NS	6.173121	

Comment [KK23]: The p-value which is the signnificant value should be written like this ≤ or ≥ 0.05 depending on your statistical analysis but NOT CD (*P* =.05) the way you have presented it. Kindly apply this in every table please

Comment [KK24]: I recommend you arrange all your tables like this where you combine the mean ± standard deviation or standard error e.g., under N harvest index, you report the Mean±Standard deviation.

3.3 Nutrient Use Efficiency

3.3.1 Partial factor productivity

Varieties had no significant influence on the partial factor productivity of nutrients (N, P, K, and S). Spacing treatments had a significant impact on the PFP of nutrients. Intense plant-to-plant spacing of 10 cm resulted in the highest PFP of nutrients, which was significantly greater than any other treatment. The widest spacing treatment of 20 cm resulted in the lowest values of PFP.

Comment [KK25]: Kindly refer to my previous comments. If significant please insert p≤0.05 orp≥0.05 if not significant

Comment [KK26]: Please read and follow the journal guideline for uniformity, whether to present results and discussion sections separately or to combine them. You start by describing the results of each table under sub-heading then tables of results of that particular sub-heading is inserted after description

3.3.2 Internal efficiency of nutrients

Nitrogen internal efficiency (NIE) was not influenced by the genotype but was significantly affected by the spacing. 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. With variety PS 1092 exhibiting 3.9% higher phosphorus internal efficiency (PIE) than SL 958, PIE was significantly affected by varieties. Although the effect of spacing on PIE was not significant, higher values of PIE were observed for wider-spaced plants. Potassium internal efficiency (PoIE) did not show a varietal effect. Intense spacing significantly influenced the PoIE. 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 significantly higher at wider spacings as compared to narrow spacings. SIE was reported to be the maximum at 15 cm plant-to-plant spacing.

3.3.3 Nutrient Harvest Index

Varieties had no significant influence on the nutrient harvest index of nitrogen, phosphorus, potassium, and sulfur. The nitrogen harvest index was significantly influenced by spacing treatments. Wider spacing resulted in a higher harvest index of nitrogen, with the maximum harvest index at the plant-to-plant spacing of 15 cm. The harvest index of phosphorus was also higher at wide spacing and lower at narrow spacing, although the differences were not significant. The harvest index of potassium was not significantly influenced by plant-to-plant spacing. The harvest index of sulfur was significantly affected by the spacing between plants. Treatment with the widest spacing (20 cm) resulted in the highest sulfur harvest index, while the lowest spacing of 5 cm resulted in the lowest values of the sulfur harvest index. Overall, wide spacing resulted in a higher nutrient harvest index as compared to narrow spacing treatments.

4. CONCLUSION

~~In summary, the cultivation of soybean varieties in a ridge and furrow plant system under an intensified spacing system represents an exciting avenue for optimizing nutrient content and uptake. By systematically analyzing the interplay between plant spacing, nutrient uptake, and nutrient use efficiency, it can be concluded that: Firstly~~, higher nutrient content and uptake in soybean seeds ~~can be~~is achieved by intensified sowing at a plant-to-plant spacing of 10 cm~~. Secondly,~~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. ~~This study contributes to the existing body of knowledge by shedding light on the complex interactions between nutrient dynamics and agronomic management, thereby providing a foundation for informed decision-making in soybean cultivation.~~

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Comment [KK28]: This is the space for recommendation for further studies steming from your conclusion, kindly insert

Comment [KK29]: This is the space for declaration of conflict of interest, please insert

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Comment [KK30]: Please write these in full throughout the references

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