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Influence of spacing and nutrition on growth and quality of lettuce (*Lactuca sativa* L.) under protected cultivation

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Abstract
This research was done to investigate the influence of spacing and nutrition on its growth and quality under protected cultivation of lettuce (*Lactuca sativa* L.) during *Rabi* of 2021-22 at ICAR-KVK, Hadonahalli of Karnataka. It was undertaken with Factorial Randomized Complete Block Design, to study the application of three different spacing such as 45×22.5 cm, 45×30 cm and 45×45 cm and three nutrient levels such as 75%, 100% and 125% of Recommended Dose of Fertilizers (RDF) along with 25 t/ha FYM. The results revealed that plant height (38.12 cm) were recorded significantly higher at 45 cm × 22.5 cm spacing. Higher number of leaves (18.26), plant spread (32.54 cm), leaf area (290.28 cm^2), chlorophyll content (48.40 SPAD), vitamin-c (40.43 mg 100 g-1), firmness (2.75) and shelf life (9 days) were recorded at 45 cm × 45 cm spacing. The higher plant height (37.65 cm), number of leaves (18.51), plant spread (32.33 cm), leaf area (268.42 cm^2), chlorophyll content (47.33 SPAD), vitamin-c (40.19 mg 100 g^{-1}), firmness (2.50) and shelf life (8 days) were recorded at 125% RDF. Thus, optimal spacing and well enhanced nutrition made critical improvements concerning growth and quality of lettuce under protected cultivation.

Keywords: Growth, lettuce, spacing, nutrition, chlorophyll and quality

1. Introduction
Lettuce (*Lactuca sativa* L.) an annual leafy herb belongs to the family Asteraceae with chromosome number 2n=18, is one of the most popular salad crops and occupies the largest production area among salad crops in the world. It is popular for its delicate, crispy texture and slightly bitter taste with milky juice when fresh (Squire *et al*., 2007) [9]. India ranks third in production of lettuce, occupying 4 per cent of the world total production. It is being grown for over 2500 years and various forms of lettuce are known since 500 B. C.

It is a self-pollinated annual plant. It forms a deep taproot with largely horizontal lateral roots, most densely near the soil surface for water and nutrient absorption (Deshpande and Salunkhe, 2008) [3]. Nearly sessile leaves are spirally arranged in a dense rosette on the often-shortened stem. There is considerable diversity in colour, shape, surface, margin and texture of leaves among different types and forms of lettuce. Leaf margins may be entire, lobed, incised, indented or undulating.

With the increase in population, the demand for the crop has significantly increased which has led to extensive use of inorganic fertilizers with least consideration for soil health, which is a critical factor for realizing sustainable yield of any vegetable crop. Besides this, the residual effects of inorganic fertilizers on environment, underground water resources, soil micro-flora, vegetables and vegetable products is a matter of great concern. The residual toxicity level is reported to be more in vegetables and fruits as compared to grains. The ill effects of chemicals in agriculture has been well documented (Carson, 1962) [2].

Plant spacing for lettuce cultivation is an important criteria for attaining maximum vegetative growth and an important aspect of crop production for maximizing the yield. Optimum plant spacing ensures judicious use of resources and makes the intercultural operations easier. It helps to increase the number of leaves and healthy foliage. Densely planted crop obstruct the proper growth and development.

On the other hand, wider spacing ensures the basic nutritional requirements but decrease the total number of plants as well as yield may be increased up to 25 per cent by using optimum spacing in leafy vegetable (Bansal *et al.*, 2004) [1].

For realizing high yield of any vegetable crop, soil health is a critical factor. The yield per unit area of lettuce is very low in India as compared to developed countries. This is probably due to lack of technical knowledge in its production aspects, especially in its nutritional requirement. Lettuce is a poor forager with a small root system; therefore, the surface soil should be well supplied with nutrients. The objective of increased yield and quality of crop can be achieved through integrated nutrient management coupled with optimum plant population.

Understanding the crop response to plant density and nutrition, it is crucial for maximizing lettuce yield. Further, due to climatic and cultivar differences, the optimal plant spacing might be seasonal and cultivar dependent.

2. Materials and Methods

Experimental site was conducted in the *Rabi* season of 2021-2022 at ICAR-Krishi Vigyan Kendra, Hadonahalli, Doddaballapur Taluk, of Bengaluru Rural District, Karnataka. The site is located at an elevation of 924 m MSL and has a coordinate position of 13°05′ N and 77°34′ E, thus falling under the Eastern Dry Zone of Karnataka. The soil is red sandy loam and well drained with uniform texture. The research was executed in a Factorial Randomized Complete Block Design (F-RCBD) with three replications and nine treatment combinations. An area of 216 m² constituted an experimental field with 27 plots, measuring 4.5 m × 1 m each, and 0.5 m separation between plots and 0.6 m between replications. Spacing level consists of S_1 (45 cm × 22.5 cm), S_2 (45 cm × 30 cm) and S_3 (45 cm × 45 cm) and nutrition level F_1 (100% RDF), F_2 (75% RDF) and F_3 (125% RDF). This factorial setup resulted in a total of nine treatment combinations (S_1F_1 to S_3F_3). The Iceberg lettuce variety was used, known for its vigorous head formation and crispy texture and transplanted in early morning hours to minimize transpiration shock. Harvesting was done uniformly 60 days after transplanting. Mature heads were cut using sharp knives for fresh weight and quality assessments. Five randomly chosen plants per plot were observed for growth and quality metrics. Additionally, soil factors were evaluated both prior to and following harvest. Observations were recorded on growth parameters like plant height, number of leaves, plant spread and leaf area. The quality parameters recorded were chlorophyll content, shelf life, vitamin-C and firmness.

Table 1: Tabular representation of growth and quality parameters, methods of measurement and time of recording

Parameter	Measurement Method	Time of Recording
Plant Height (cm)	Measured from base to tip	15, 30, 45, and 60 DAT
Number of Leaves	Manual count	15, 30, 45, and 60 DAT
Plant Spread (cm)	Average N-S and E-W spread	At harvest
Leaf Area (cm²)	Measured using a leaf area meter	At harvest
Chlorophyll Content	SPAD meter reading	45 DAT
Vitamin C Content	Titration with 2,6-dichlorophenol-indophenol	At harvest
Firmness	5-point hand compression method (Kader *et al*., 1973) [6]	At harvest
Shelf Life (days)	Days to spoilage at room temperature	Post-harvest daily monitoring

Results and Discussion

Growth parameters

Spacing and nutrient levels had a significant impact on all growth parameters of lettuce throughout the crop duration. Plant height progressively increased with crop age and was significantly higher under the closer spacing of 45 cm × 22.5 cm (S_1), which recorded a height of 38.12 cm at 60 DAT (Table 2). This increase is likely due to greater competition for light, nutrients and space, causing plants to grow taller. On the other hand, wider spacing of 45 cm × 45 cm (S3) recorded the shorter plants (35.18 cm). Further, insufficient space for spread or low plant canopy area and energy diverted upward increasing height instead of spreading due to lower area available to each plant and increased in height at narrow spacing 45 cm × 22.5 cm. Similar kind of results were reported by Singh *et al*. (2006). Among nutrient treatments, the taller plants (37.65 cm) were recorded under 125% RDF (F_3), whereas the shorter (35.83 cm) was observed under 75% RDF (F_2), indicating a strong positive role of nitrogen and phosphorus in promoting vegetative growth. Fertilizers induce the growth of the plant through active protein metabolism, transportation of photosynthates and synthesis of nucleic acid and proteins. Hence, during the vegetative stage, nitrogen nutrition of the plant to a large extent controls the growth of plant. These results are in agreement with findings of Haque *et al*. (2015) [5] and Prasad *et al*. (2010) [7].

Similarly, the number of leaves per plant increased significantly with wider spacing and higher nutrient levels. The higher number of leaves (18.26) was observed under S_3, while S_1 recorded the least (17.27), (Table 3). Among nutrients, F_3 produced the most leaves (18.51) and F_2 the fewer (17.26). The wider spacing allowed more light and air penetration, supporting healthier leaf formation. Though interaction effects were statistically non-significant, the combination S_3F_3 numerically produced the higher leaf count (19.56). Plant spread and leaf area also followed a similar trend. Wider spacing (S_3) resulted in significantly greater plant spread (32.54 cm) and leaf area (290.28 cm²) as shown in Table 4 and Figure 2. A comparable study was done by and Thirupal *et al*. (2014) [10]. Likewise, F_3 recorded the higher spread (32.33 cm) and leaf area (268.42 cm²). Similar findings were reported by Hasan *et al*. (2017) [4] highlighting the positive influence of ample spacing and nutrient availability. The interaction between spacing and nutrition was non-significant but maximum plant spread (33.74 cm) and leaf areas (325.33 cm²) were observed under S_3F_3.

Table 2: Effect of spacing, nutrition and their interaction on plant height of lettuce

Treatment	Plant height (cm)			
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**
Spacing (S)				
S_1	15.90	22.22	29.87	38.12
S_2	14.04	21.26	27.86	36.90
S_3	12.11	19.54	27.17	35.18
F-test	*	*	*	*
S.EM±	0.16	0.20	0.62	0.19
CD (5%)	0.47	0.45	1.87	0.58
Nutrition (F)				
F_1	13.94	21.11	28.12	36.72
F_2	12.48	20.17	26.77	35.83
F_3	15.63	21.75	30.00	37.65
F-test	*	*	*	*
S.EM±	0.16	0.20	0.62	0.19
CD (5%)	0.47	0.45	1.87	0.58
Interaction (S×F)				
S_1F_1	15.66	22.16	28.79	37.99
S_1F_2	14.19	21.47	26.44	37.22
S_1F_3	17.86	23.03	33.34	39.15
S_2F_1	14.00	21.50	28.18	36.83
S_2F_2	12.33	20.03	26.42	35.86
S_2F_3	15.80	22.24	28.98	38.01
S_3F_1	12.17	19.67	27.38	35.33
S_3F_2	10.93	19.00	26.44	34.42
S_3F_3	13.24	19.97	27.68	35.78
F-test	NS	NS	NS	NS
S.EM±	0.27	0.35	1.08	0.33
CD (5%)	0.81	1.04	3.23	1.00

Table 3: Effect of spacing, nutrition and their interaction on number of leaves of lettuce

Treatment	Number of leaves per plant			
	15 DAT	**30 DAT**	**45 DAT**	**At harvest**
Spacing (S)				
S_1	5.91	11.40	13.45	17.27
S_2	6.00	12.13	14.01	17.86
S_3	6.47	12.33	14.97	18.26
F-test	*	*	*	*
S.EM±	0.14	0.1778	0.23	0.2362
CD (5%)	0.42	0.53	0.69	0.70
Nutrition (F)				
F_1	6.11	11.82	13.99	17.61
F_2	5.78	11.34	13.66	17.26
F_3	6.49	12.70	14.93	18.51
F-test	*	*	*	*
S.EM±	0.14	0.1778	0.2317	0.2362
CD (5%)	0.42	0.53	0.69	0.70
Interaction (S×F)				
S_1F_1	6.07	11.56	13.40	17.06
S_1F_2	5.33	10.90	13.33	16.93
S_1F_3	6.33	11.73	14.06	17.80
S_2F_1	5.47	11.83	14.16	17.70
S_2F_2	6.45	11.53	13.66	17.40
S_2F_3	5.93	13.03	14.20	18.46
S_3F_1	6.17	12.06	14.40	18.06
S_3F_2	6.53	11.60	13.96	17.43
S_3F_3	7.30	13.33	16.53	19.56
F-test	NS	NS	NS	NS
S.EM±	0.24	0.30	0.40	0.40
CD (5%)	0.73	0.92	1.20	1.22

Table 4: Effect of spacing and nutrition on plant spread and leaf area of lettuce

Treatment	Plant spread (cm)	Leaf area (cm^2)
Spacing (S)		
S_1	30.62	208.21
S_2	31.53	245.71
S_3	32.54	290.28
F-test	*	*
S.EM±	0.16	7.26
CD (5%)	0.48	21.76
Nutrition(F)		
F_1	31.52	253.92
F_2	30.84	221.87
F_3	32.33	268.42
F-test	*	*
S.EM±	0.16	7.26
CD (5%)	0.48	21.76
Interaction (S×F)		
S_1F_1	30.72	209.75
S_1F_2	30.13	200.01
S_1F_3	31.02	214.88
S_2F_1	31.36	244.45
S_2F_2	30.99	227.65
S_2F_3	32.23	265.05
S_3F_1	32.47	286.64
S_3F_2	31.41	237.95
S_3F_3	33.74	325.33
F-test	NS	NS
S.EM±	0.28	12.57
CD (5%)	0.83	37.69

Table 5: Effect of spacing and nutrition on quality parameters of lettuce

Treatment	Chlorophyll content (SPAD value)	Vitamin-C content (100 mg^{-1})
Spacing (S)		
S_1	38.54	32.40
S_2	45.56	36.97
S_3	48.80	40.43
F-test	*	*
S.EM±	0.57	0.28
CD (5%)	1.70	0.83
Nutrition(F)		
F_1	44.06	36.84
F_2	41.50	32.76
F_3	47.33	40.19
F-test	*	*
S.EM±	0.57	0.28
CD (5%)	1.70	0.83
Interaction (S×F)		
S_1F_1	37.63	32.07
S_1F_2	34.73	28.82
S_1F_3	43.25	36.30
S_2F_1	46.38	38.20
S_2F_2	43.71	32.33
S_2F_3	46.45	40.37
S_3F_1	48.17	40.27
S_3F_2	46.08	37.13
S_3F_3	52.16	43.90
F-test	NS	NS
S.EM±	0.98	0.48
CD (5%)	2.94	1.44

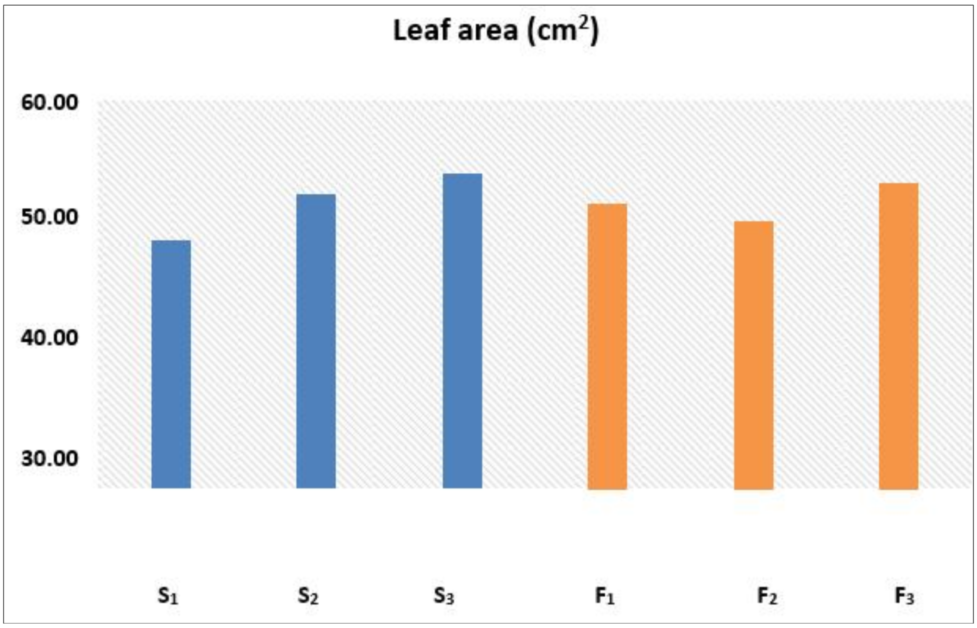

Fig 1: Effect of spacing and nutrition on leaf area in lettuce

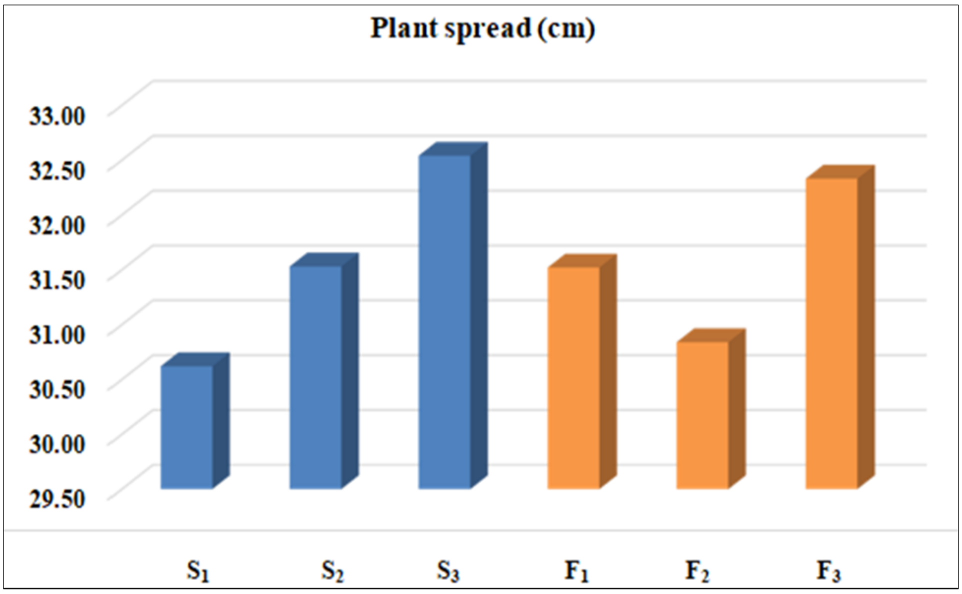

Fig 2: Effect of spacing and nutrition on leaf area in lettuce

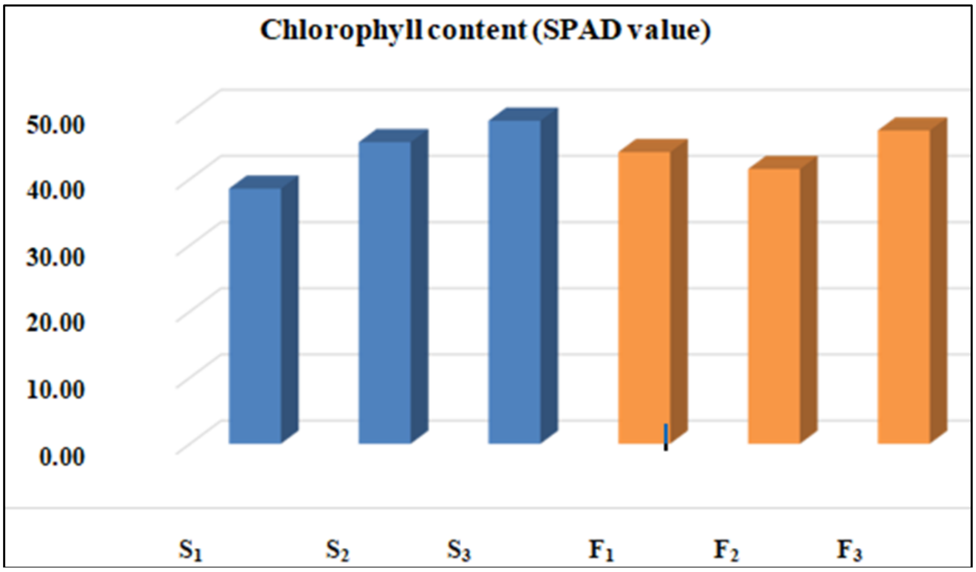

Fig 3: Effect of spacing and nutrition on chlorophyll in lettuce

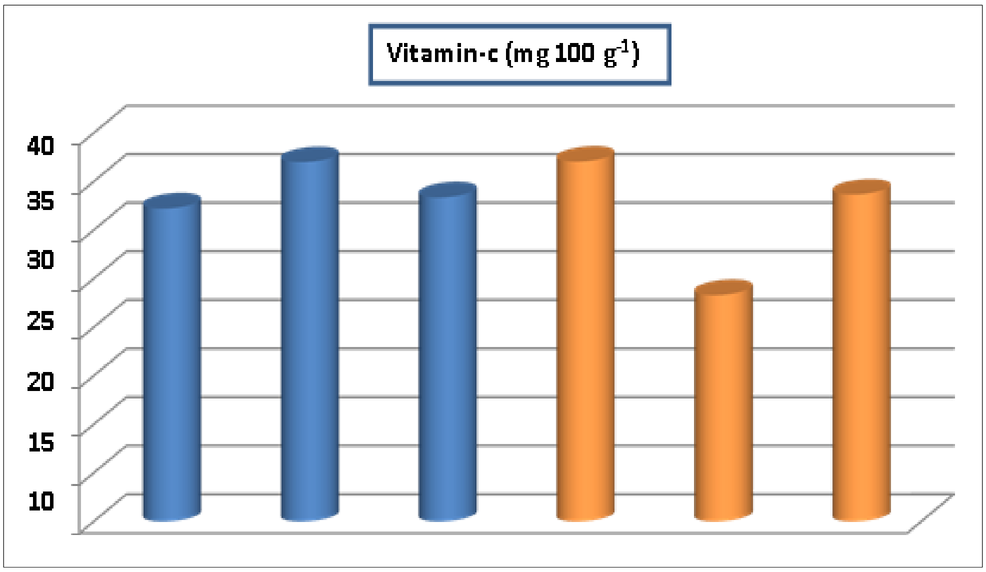

Fig 4: Effect of spacing and nutrition on vitamin-c content of lettuce

Quality parameters

Spacing and nutrient levels also had a significant impact on quality parameters such as chlorophyll content, vitamin C, firmness and shelf life. As shown in Table 5 and Figure 3, chlorophyll content was significantly higher in wider spacing (S_3: 48.80 SPAD units) and higher nutrient level (F_3: 47.33 SPAD). S_3F_3 recorded the maximum chlorophyll content (52.16 SPAD), though interaction was statistically non-significant. Similarly, vitamin C content **(**Table 5, Figure 4) was higher in S_3 (40.43 mg/100 g) and F_3 (40.19 mg/100 g). This increase may be due to better nutrient uptake, especially nitrogen and micronutrients, in less crowded plantings. The maximum vitamin C (43.90 mg /100 g) was found in S_3F_3. Firmness and shelf life followed the same trend **(**Table 6). Lettuce heads were firmer under S_3 (2.75) and F_3 (2.50), with the lower score (best firmness) recorded in S_3F_3 (2.25). This might be due to sufficient availability of spacing and availability of sufficient amount of nutrients. So there was less competition among plants in case of wider spacing compared to narrow spacing.

Shelf life was longer in S_3 (9 days) and F_3 (8 days), again with the maximum of 9 days in the S_3F_3 combination. This might be due to the sufficient availability of spacing and sunlight for better growth and development of lettuce and plants received sufficient amount of nutrients. So there was less competition among plants in case of wider spacing for resources. These findings support the idea that better-spaced, well-nourished plants develop stronger physiological characteristics and store better post-harvest.

Table 5: Effect of spacing and nutrition on firmness and shelf life content of lettuce

Treatment	Firmness (Scores)	Shelf life (Days)
Spacing (S)		
S_1	3.75	7
S_2	3.50	8
S_3	2.75	9
F-test	*	*
S.EM±	0.16	0.09
CD (5%)	0.49	0.28
Nutrition(F)		
F_1	3.50	7
F_2	3.75	6
F_3	2.50	8
F-test	*	*
S.EM±	0.16	0.09
CD (5%)	0.49	0.28
Interaction (S×F)		
S_1F_1	3.25	7
S_1F_2	3.75	6
S_1F_3	2.75	7
S_2F_1	3.25	8
S_2F_2	3.50	7
S_2F_3	2.50	8
S_3F_1	3.25	8
S_3F_2	3.50	8
S_3F_3	2.25	9
F-test	NS	NS
S.EM±	0.98	0.16
CD (5%)	2.94	0.49

Conclusion

The study clearly demonstrated that both spacing and nutrient levels significantly influence the growth, yield, quality, and economic returns of lettuce (*Lactuca sativa* L.) under protected cultivation. Wider spacing (45×45 cm) improved individual plant parameters such as plant spread, leaf area, fresh and dry weight, chlorophyll content, and vitamin C concentration, leading to better produce quality and longer shelf life. Thus, for optimizing lettuce production under protected conditions, a combination of 45×45 cm spacing with 125% RDF is recommended to achieve the best balance between high productivity, superior quality and maximum profitability. Future research could further explore the role of integrated nutrient management with organic sources to enhance sustainability in protected cultivation systems.

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