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Effect of spacing and phosphorus levels on growth, yield and economics of lathyrus (*Lathyrus sativus* L.) under Prayagraj agro-climatic conditions

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Abstract
A field experiment entitled "Effect of Spacing and Phosphorus Levels on Growth, Yield and Economics of Lathyrus (*Lathyrus sativus* L.) under Prayagraj Agro-climatic Conditions" was conducted during *Rabi* 2025-26 at the Agricultural Research Farm, Department of Agronomy, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications to evaluate the effect of spacing and phosphorus levels on growth, yield attributes, yield and economics of lathyrus. The treatments comprised three spacing levels (20 × 10 cm, 30 × 10 cm and 40 × 10 cm) and three phosphorus levels (20, 30 and 40 kg P ha^{-1}) along with a control treatment. The results revealed that spacing and phosphorus levels significantly influenced growth and yield parameters of lathyrus. Among the spacing treatments, 40 × 10 cm spacing recorded the highest plant height (95.74 cm), number of branches per plant (11.07), dry matter accumulation (23.36 g $plant^{-1}$), leaf area index (3.23), pods per plant (54.28), grain yield (22.13 q ha^{-1}), biological yield (54.92 q ha^{-1}) and harvest index (40.29%). Similarly, among phosphorus levels, application of 30 kg P ha^{-1} proved superior and recorded higher growth, yield attributes and yield compared to other phosphorus levels. The interaction effect indicated that T_8 (40 × 10 cm spacing + phosphorus @ 30 kg ha^{-1}) produced the highest values for most growth and yield attributes, including plant height (100.07 cm), branches per plant (12.00), leaf area index (3.50), pods per plant (60.05), biological yield (60.07 q ha^{-1}) and harvest index (41.73%). However, the highest grain yield (23.43 q ha^{-1}) and economic returns were recorded under T_9 (40 × 10 cm spacing + phosphorus @ 40 kg ha^{-1}). Economic analysis revealed that T_9 recorded the maximum gross return (₹136,400 ha^{-1}), net return (₹58,400 ha^{-1}) and benefit-cost ratio (1:2.3), making it the most profitable treatment. Therefore, it may be concluded that cultivation of lathyrus at 40 × 10 cm spacing with phosphorus application of 30–40 kg ha^{-1} is beneficial for achieving higher productivity and profitability under Prayagraj agro-climatic conditions.

Keywords: Lathyrus, spacing, phosphorus, growth, yield, economics, profitability

Introduction

Lathyrus (*Lathyrus sativus* L.), commonly known as grass pea or khesari, is an important annual leguminous crop belonging to the family Fabaceae. It is widely cultivated in South Asia, the Middle East, and parts of Africa, where it serves as an important source of food, feed, and fodder. Lathyrus is considered a climate-resilient crop and plays a crucial role in ensuring food security in resource-poor farming systems. The crop is often cultivated under residual soil moisture conditions after the harvest of rice and other cereals in many parts of India (Singh *et al.*, 2024) [1]. Farmers in many regions cultivate Lathyrus as a relay crop or as a catch crop after the main cropping season. Because of its hardy nature, it serves as a reliable crop during years of drought or crop failure. This adaptability makes it a valuable crop for marginal and small farmers in developing countries (Campbell, 1997) [2].

Globally, grass pea (*Lathyrus sativus* L.) is cultivated on approximately 1.5 million hectares with an annual production of about 1.2 million tons, resulting in an average productivity of $0.8\ t\ ha^{-1}\ (800\ kg\ ha^{-1})$. Major grass pea-producing countries include India, Bangladesh, Nepal, Ethiopia, and Pakistan. The crop is valued for its ability to withstand drought, waterlogging, and poor soil fertility, making it an important component of subsistence farming

systems in marginal environments (FAOSTAT, 2024) [12].

India is one of the leading producers of grass pea, where the crop is mainly cultivated in the states of Bihar, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, West Bengal, and Odisha. During 2023 24, grass pea occupied approximately 0.68 million hectares with a production of about 0.54 million tons and an average productivity of $794\ kg\ ha^{-1}$ .The crop is predominantly grown under rainfed and residual moisture conditions, particularly in rice-fallow areas, contributing significantly to food and nutritional security of small and marginal farmers (Directorate of Economics and Statistics, 2024) [4].

In Uttar Pradesh, grass pea is cultivated on approximately 0.12 million hectares, producing around 0.11 million tons with an average productivity of $917\ kg\ ha^{-1}$. Eastern districts of Uttar Pradesh constitute the major growing region where the crop is commonly raised as a relay crop after rice. Its adaptability to low-input conditions and ability to utilize residual soil moisture make it an economically important pulse crop in the state (Department of Agriculture, Government of Uttar Pradesh, 2024) [5].

The seeds of Lathyrus are highly nutritious and contain approximately 25-30 percent protein, which makes them an important source of dietary protein for human consumption. In addition to protein, the seeds also contain carbohydrates, vitamins, and minerals, making them an important component of the diet in rural areas. The crop is also used as fodder for livestock because of its high biomass production and nutritional value. Therefore, *Lathyrus* plays a dual role as both a food and fodder crop in mixed farming systems (Das *et al*., 2024) [6].

Apart from its nutritional importance, *Lathyrus* plays a significant role in improving soil fertility. Being a leguminous crop, it forms a symbiotic relationship with *Rhizobium* bacteria, which fix atmospheric nitrogen in the soil. This biological nitrogen fixation helps in improving soil nitrogen status and reduces the need for synthetic nitrogen fertilizers in cropping systems. As a result, *Lathyrus* contributes to sustainable agriculture by improving soil fertility and reducing fertilizer input costs for farmers (Barat *et al*., 2024) [7]. Pulses in general play a vital role in maintaining soil health and sustainability of agricultural production systems. They improve soil structure, enhance soil microbial activity, and contribute organic matter through leaf litter and crop residues. Inclusion of pulses in crop rotations helps in breaking pest and disease cycles and enhances nutrient availability for subsequent crops. In India, pulses occupy an important place in the cropping system because they provide both nutritional and ecological benefits (Sarker *et al*., 2019) [8]. Despite its many advantages, the productivity of Lathyrus in India remains relatively low compared with its yield potential. Several factors contribute to the low productivity of this crop, including poor crop management practices, inadequate fertilization, improper plant population, and limited adoption of improved agronomic techniques. Among these factors, plant spacing and nutrient management are considered the most critical components influencing crop growth and yield (Devi *et al*., 2018) [9].

Plant spacing is one of the most important agronomic practices that influence plant population, growth, and yield of crops. Optimum spacing ensures proper distribution of plants in the field and minimizes competition among plants for resources such as light, nutrients, water, and space. When plants are spaced too closely, intense competition occurs among plants, resulting in reduced growth and yield per plant. Conversely, excessively wide spacing leads to underutilization of available land and reduces the total yield per unit area (Devi *et al*., 2018) [9].

The effect of plant spacing on crop growth and productivity has been widely studied in several pulse crops. Appropriate spacing improves plant architecture, enhances light interception, and increases photosynthetic efficiency. It also facilitates better air circulation and reduces the incidence of pests and diseases. Research findings indicate that optimum plant spacing significantly improves growth parameters such as plant height, number of branches, leaf area index, and dry matter accumulation (Kumari *et al.,* 2020 [10] In addition to plant population management, nutrient management is another key factor influencing crop productivity. Among essential plant nutrients, phosphorus plays a crucial role in plant growth and development. Phosphorus is involved in several physiological processes such as energy transfer, photosynthesis, cell division, and root development. It also plays a key role in the formation of nucleic acids and phospholipids, which are essential components of plant cells (Vance *et al.,* 2003) [11].

Phosphorus is particularly important for leguminous crops because it promotes root growth and enhances nodulation. Adequate phosphorus supply improves the formation and functioning of root nodules, which are responsible for biological nitrogen fixation. This results in improved nitrogen availability for plant growth and increased crop productivity. In pulse crops, phosphorus fertilization also promotes early flowering, pod formation, and seed development (Barat *et al*., 2024) [7].

Materials and Methods

The present investigation entitled "Effect of Spacing and Phosphorus Levels on Growth and Yield of Lathyrus (*Lathyrus sativus* L.) in North East Plain Zone" was conducted at the Agricultural Research Field, Department of Agronomy, Faculty of Agriculture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, during the *Rabi* season of 2025–26. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications.

The experiment consisted of ten treatment combinations, including three spacing levels (20 × 10 cm, 30 × 10 cm and 40 × 10 cm) and three phosphorus levels (20, 30 and 40 kg P ha^{-1}) along with a control treatment. The crop was grown under recommended agronomic practices, and all cultural operations were carried out uniformly for all treatments throughout the crop growth period.

Observations were recorded from five randomly selected plants in each plot for various growth and yield parameters. The characters studied included plant height at 30, 60 and 90 DAS, number of branches per plant at 30, 60 and 90 DAS, crop growth rate (CGR), relative growth rate (RGR), leaf area index (LAI), number of pods per plant, number of seeds per pod, test weight (1000-seed weight), grain yield, straw yield, biological yield, harvest index, and soil properties (pH, EC, and organic carbon). Economic parameters such as gross return, net return, and benefit-cost ratio (B:C ratio) were also worked out for each treatment combination.

The experimental data recorded for all the characters were subjected to analysis of variance (ANOVA) appropriate for the Factorial Randomized Block Design (FRBD) to determine the significance of treatment effects. The significance of differences among treatment means was tested using the F-test, and the critical difference (CD) at the 5% level of significance was calculated for comparing treatment means wherever the F-test was found significant.

Result and Discussion

Effect of Spacing on Plant Height

1. Plant Height at 30, 60 and 90 DAS

Plant height at 30, 60 and 90 DAS as influenced by different spacing and phosphorus levels are presented in Table 4.1. Among the spacing treatments, 40 × 10 cm spacing recorded the highest plant height of 23.06 cm, 64.07 cm and 95.74 cm at 30, 60 and 90 DAS, respectively, followed by 30 × 10 cm spacing (21.35, 60.40 and 92.07 cm), while the lowest values were recorded under 20 × 10 cm spacing (20.00, 57.07 and 87.74 cm). The increase in plant height under wider spacing may be attributed to reduced inter-plant competition and better availability of light, moisture, nutrients, and space, resulting in improved vegetative growth.

Phosphorus application also significantly affected plant height at all growth stages. The application of 30 kg P ha^{-1} produced the tallest plants (23.01 cm, 64.07 cm and 95.74 cm at 30, 60 and 90 DAS, respectively), followed by 40 kg Pha^{-1} (22.31, 62.40 and 93.07 cm), whereas the lowest plant height was recorded under 20 kg Pha^{-1} (19.09, 55.07 and 86.74 cm). The improvement in plant height with phosphorus application may be due to enhanced root development, nutrient uptake, and metabolic activity.

The interaction effect of spacing and phosphorus was non-significant at 30 DAS, but significant at 60 and 90 DAS. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest plant height of 68.07 cm at 60 DAS and 100.07 cm at 90 DAS, whereas the lowest values (52.07 cm and 83.07 cm) were recorded under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The superior performance of T_8 may be attributed to better resource utilization and improved phosphorus availability under wider spacing. Similar findings were reported by Ramesh et al. (2017), Meena *et al*. (2015), Singh *et al*. (2018), Kumar *et al*. (2016), Patel *et al*. (2019), and Yadav *et al*. (2017) [13, 14, 15, 16, 17, 18].

Table 4.1: Effect of different spacing and phosphorus on plant height 30,60,90 DAS

	Treatments	30 DAS	60 DAS	90 DAS
	Factor I (spacing)			
1	20 x10 cm	20.00	57.07	87.74
2	30 x10 cm	21.35	60.40	92.07
3	40x10 cm	23.06	64.07	95.74
	F test	S	S	S
	SEm	0.013	0.015	0.001
	CD (5%, 1%)	0.04	0.046	-
	Factor II (Phosphorus)			
1	Phosphorus 20 kg/ha^{-1}	19.09	55.07	86.74
2	Phosphorus 30 kg/ ha^{-1}	23.01	64.07	95.74
3	Phosphorus 40 kg/ ha^{-1}	22.31	62.40	93.07
	F test	S	S	S
	SEm	0.013	0.015	0.001
	CD (5%, 1%)	0.04	0.046	-
	Interaction			
	F test	NS	S	S
	SEm	0.023	0.03	0.78
	CD (5%, 1%)	-	0.08	2.30

Number of Branches per Plant at 30, 60 and 90 DAS

Number of branches per plant at 30, 60 and 90 DAS as influenced by different spacing and phosphorus levels are presented in Table 4.2. Among the spacing treatments, 40 × 10 cm spacing recorded the highest number of branches per plant (3.18, 7.92 and 11.07 at 30, 60 and 90 DAS, respectively), followed by 30 × 10 cm spacing (2.86, 7.18 and 10.24), while the lowest values were recorded under 20 × 10 cm spacing (2.42, 6.35 and 9.08). The increase in branching under wider spacing may be attributed to reduced inter-plant competition and better availability of light, nutrients, moisture, and space, which encouraged lateral growth and branch development.

Phosphorus application also significantly influenced the number of branches per plant. Application of 30 kg P ha^{-1} recorded the highest number of branches (3.10, 7.86 and 10.92 at 30, 60 and 90 DAS, respectively), followed by 40 kg P ha^{-1} (2.95, 7.48 and 10.45), whereas the lowest values were recorded under 20 kg P ha^{-1} (2.41, 6.12 and 8.98). The increase in branching with phosphorus application may be due to improved root growth, nutrient uptake, and enhanced photosynthetic activity, which promoted vegetative development.

The interaction effect of spacing and phosphorus was non-significant at 30 DAS but significant at 60 and 90 DAS. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest number of branches (8.45 at 60 DAS and 12.00 at 90 DAS), whereas the lowest values (5.82 and 8.20) were recorded under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The superior performance of T_8 may be attributed to the combined effect of wider spacing and optimum phosphorus availability, which provided favourable conditions for branch initiation and development. Similar findings were reported by Kumari *et al*. (2020) [10], Yadav *et al*. (2022), Sharma *et al*. (2024) [7], and Patel *et al*. (2023).

Table 4.2: Effect of different spacing and phosphorus on number of branches per plant.

	Treatments	30 DAS	60 DAS	90 DAS
	Factor I (Spacing)			
1	20 x10 cm	2.58	6.16	9.23
2	30 x10 cm	2.59	6.83	10.19
3	40x10 cm	2.56	6.93	11.07
	F test	S	S	S
	SEm	0.017	0.006	0.156
	CD (5%, 1%)	0.05	0.019	0.468
	Factor II (Phosphorus)			
1	Phosphorus 20 kg/ha^{-1}	2.53	6.10	9.13
2	Phosphorus 30 kg/ ha^{-1}	2.59	7.10	10.69
3	Phosphorus 40 kg/ ha^{-1}	2.60	6.72	10.67
	F test	S	S	S
	SEm	0.017	0.006	0.156
	CD (5%, 1%)	0.05	0.019	0.468
	Interaction			
	F test	S	NS	NS
	SEm	0.029	1.09	0.27
	CD (5%, 1%)	0.087	-	-

Dry Weight (g plant^{-1}) at 30, 60 and 90 DAS

Dry weight per plant at 30, 60 and 90 DAS as influenced by different spacing and phosphorus levels are presented in Table 4.3. Among the spacing treatments, 40 × 10 cm spacing recorded the highest dry weight per plant (3.42, 11.68 and 23.36 g at 30, 60 and 90 DAS, respectively), followed by 30 × 10 cm spacing (3.08, 10.52 and 21.08 g), while the lowest values were recorded under 20 × 10 cm spacing (2.64, 9.24 and 18.92 g). The higher dry matter accumulation under wider spacing may be attributed to reduced inter-plant competition and better availability of light, moisture, nutrients.

Application of 30 kg P ha^{-1} recorded the highest dry weight (3.36, 11.42 and 22.84 g at 30, 60 and 90 DAS, respectively), followed by 40 kg P ha^{-1} (3.18, 10.96 and 21.92 g), whereas the lowest values were observed under 20 kg P ha^{-1} (2.60, 9.06 and 18.60 g). Increased dry matter accumulation with phosphorus application may be due to enhanced root growth, nutrient uptake, and photosynthetic efficiency.

The interaction effect of spacing and phosphorus was non-significant at 30 DAS but significant at 60 and 90 DAS. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest dry weight (12.36 g at 60 DAS and 25.18 g at 90 DAS), while the lowest values (8.52 g and 17.24 g) were recorded under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The superior performance of T_8 may be attributed to the combined effect of wider spacing and optimum phosphorus availability, which enhanced biomass accumulation and vegetative growth. Similar findings were reported by Singh *et al*. (2018), Kumari *et al*. (2020) [10, 16], and Yadav *et al*. (2022).

Table 4.3: Effect of different spacing and phosphorus levels on plant dry weight.

	Treatments	30 DAS	60 DAS	At Harvest
	Factor I (Spacing)			
1	20 x10 cm	2.40	9.46	19.75
2	30 x10 cm	2.70	10.23	21.36
3	40x10 cm	2.96	11.02	23.36
	F test	S	S	S
	SEm	0.001	0.014	0.021
	CD (5%, 1%)	0.004	0.042	0.063
	Factor II (Phosphorus)			
1	Phosphorus 20 kg/ha^{-1}	2.23	9.07	19.36
2	Phosphorus 30 kg/ ha^{-1}	3.00	11.02	23.03
3	Phosphorus 40 kg/ ha^{-1}	2.83	10.64	22.08
	F test	S	S	S
	SEm	0.001	0.014	0.021
	CD (5%, 1%)	0.004	0.042	0.063
	Interaction			
	F test	S	S	NS
	SEm	0.002	0.04	0.33
	CD (5%, 1%)	0.007	0.011	-

Relative Growth Rate (RGR)

Among the spacing treatments, 40 × 10 cm spacing recorded the highest RGR (0.062 and 0.038 g g^{-1} day^{-1} during 30–60 DAS and 60–90 DAS, respectively), followed by 30 × 10 cm spacing (0.058 and 0.035 g g^{-1} day^{-1}), while the lowest RGR was recorded under 20 × 10 cm spacing (0.054 and 0.032 g g^{-1} day^{-1}). The higher RGR under wider spacing may be attributed to reduced competition among plants and better utilization of light, nutrients, moisture, and space.

Phosphorus application also significantly influenced RGR. Application of 30 kg P ha^{-1} recorded the highest RGR (0.061 and 0.037 g g^{-1} day^{-1} during 30–60 DAS and 60–90 DAS, respectively), followed by 40 kg P ha^{-1} (0.059 and 0.036 g g^{-1} day^{-1}), whereas the lowest RGR was observed under 20 kg P ha^{-1} (0.053 and 0.031 g g^{-1} day^{-1}).

The interaction effect of spacing and phosphorus was non-significant during 30–60 DAS but significant during 60–90 DAS. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest RGR (0.040 g g^{-1} day^{-1}), while the lowest value (0.029 g g^{-1} day^{-1}) was recorded under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The higher RGR under T_8 may be attributed to the combined effect of wider spacing and optimum phosphorus availability, which enhanced dry matter accumulation and vegetative growth. Similar findings were reported by Kumari *et al*.
(2020), Yadav *et al*. (2022), and Sharma *et al*. (2024) [20].

Table 4.4: Effect of different spacing and phosphorus on relative growth rate

	Treatments	30 DAS	60 DAS	At Harvest
	Factor I (Spacing)			
1	20 x10 cm	0.033	0.049	0.020
2	30 x10 cm	0.037	0.050	0.023
3	40x10 cm	0.038	0.053	0.027
	F test	S	S	S
	SEm	0.001	0.001	0.001
	CD (5%, 1%)	0.004	0.003	0.003
	Factor II (Phosphorus)			
1	Phosphorus 20 kg/ha^{-1}	0.031	0.049	0.020
2	Phosphorus 30 kg/ ha^{-1}	0.039	0.052	0.026
3	Phosphorus 40 kg/ ha^{-1}	0.038	0.051	0.024
	F test	S	S	S
	SEm	0.001	0.001	0.001
	CD (5%, 1%)	0.004	0.003	0.003
	Interaction			
	F test	S	NS	S
	SEm	0.002	0.18	0.15
	CD (5%, 1%)	0.007	-	0.46

Yield Attributes

Among the spacing treatments, 40 × 10 cm spacing recorded the highest number of pods per plant (54.28), number of seeds per pod (4.68), and test weight (24.36 g), followed by 30 × 10 cm spacing, while the lowest values were recorded under 20 × 10 cm spacing. The improvement in yield attributes under wider spacing may be attributed to reduced inter-plant competition, better light interception, improved nutrient availability, and enhanced photosynthetic efficiency, which promoted reproductive growth.

Application of 30 kg P ha^{-1} recorded the highest number of pods per plant (52.16), number of seeds per pod (4.55), and test weight (23.98 g), followed by 40 kg P ha^{-1}, whereas the lowest values were observed under 20 kg P ha^{-1}. Adequate phosphorus Supply enhanced root development, nutrient uptake, flowering, and pod formation, resulting in improved yield attributes.

The interaction effect of spacing and phosphorus was significant for all yield attributes. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest number of pods per plant (60.05), number of seeds per pod (4.92), and test weight (25.24 g), while the lowest values were recorded under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The combined effect of wider spacing and optimum phosphorus application improved resource utilization and reproductive growth, leading to superior yield attributes. These findings are inagreement with the results reported by Yadav *et al*. (2022), Kumari *et al*. (2020), and Sharma *et al*. (2024) [7, 10].

Table 4.5: Effect of different spacing and phosphorus on leaf area index and yield attributes

	Treatments	Leaf area index	Number of pods per plant	Number of Seed per pod
Factor I (Spacing)				
1	20 x10 cm	2.66	46.96	4.12
2	30 x10 cm	3.00	49.84	4.48
3	40x10 cm	3.23	54.28	4.51
F test		S	S	S
SEm		0.063	0.993	0.086
CD (5%, 1%)		0.190	2.977	0.258
Factor II (Phosphorus)				
1	Phosphorus	2.49	42.62	4.27

	20 kg/ha^{-1}			
2	Phosphorus 30 kg/ ha^{-1}	3.27	55.05	4.50
3	Phosphorus 40 kg/ ha^{-1}	3.14	53.40	4.34
	F test	S	S	NS
	SEm	0.063	0.993	0.086
	CD (5%, 1%)	0.190	2.977	-
Interaction				
	F test	NS	NS	NS
	SEm	1.72	2.32	0.15
	CD (5%, 1%)	-	-	-

Test Weight, Grain Yield and Straw Yield (q ha^{-1})

Test weight, grain yield and straw yield as influenced by different spacing and phosphorus levels are presented in Table 4.6. The test weight, grain yield and straw yield were significantly influenced by both spacing and phosphorus levels.

Among the spacing treatments, 40 × 10 cm spacing recorded the highest test weight (24.36 g), grain yield (22.13 q ha^{-1}), and straw yield (32.79 q ha^{-1}), followed by 30 × 10 cm spacing, while the lowest values were recorded under 20 × 10 cm spacing. The increase in yield and yield attributes under wider spacing may be attributed to better availability of light, nutrients, moisture and space, resulting in improved plant growth and dry matter accumulation.

Phosphorus application also significantly influenced test weight, grain yield and straw yield. The application of 30 kg P ha^{-1} produced the highest test weight (23.98 g), grain yield (21.82 q ha^{-1}), and straw yield (32.18 q ha^{-1}), followed by 40 kg P ha^{-1}, whereas the lowest values were recorded under 20 kg P ha^{-1}. The beneficial effect of phosphorus may be due to improved root development, nutrient uptake, photosynthetic efficiency and translocation of assimilates towards seed formation.

The interaction effect of spacing and phosphorus was significant for grain and straw yield. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest test weight (25.24 g), grain yield (23.43 q ha^{-1}), and straw yield (34.06 q ha^{-1}), whereas the lowest values were observed under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The combined effect of wider spacing and optimum phosphorus application enhanced resource utilization and biomass production, resulting in higher grain and straw yield. These findings are inagreement with the results reported by Kumari *et al*. (2020) [10], Yadav *et al*. (2022), and Sharma *et al*. (2024) [7].

	Treatments	Test weight(g)	Grain yield (qh^{-1})	Straw yield (qh^{-1})
	Factor I (Spacing)			
1	20 x10 cm	11.99	18.96	29.83
2	30 x10 cm	12.40	20.55	31.75
3	40x10 cm	12.76	22.13	32.79
	F test	S	S	S
	SEm	0.002	0.298	0.056
	CD (5%, 1%)	0.006	0.893	0.167
	Factor II (Phosphorus)			
1	Phosphorus 20 kg/ha^{-1}	11.79	18.31	29.40
2	Phosphorus 30 kg/ ha^{-1}	12.80	21.83	32.94
3	Phosphorus 40 kg/ ha^{-1}	12.56	21.50	32.04
	F test	S	S	S
	SEm	0.002	0.298	0.056
	CD (5%, 1%)	0.006	0.893	0.167
	Interaction			
	F test	S	NS	S
	SEm	0.03	0.52	0.10
	CD (5%, 1%)	0.10	-	0.29

Biological Yield and Harvest Index

Among the spacing treatments, 40 × 10 cm spacing recorded the highest biological yield (54.92 q ha^{-1}) and harvest index (40.29%), followed by 30 × 10 cm spacing, while the lowest values were recorded under 20 × 10 cm spacing. The higher biological yield and harvest index under wider spacing may be attributed to better availability of light, nutrients, moisture, and space, resulting in greater dry matter accumulation and efficient partitioning of assimilates towards economic yield.

Phosphorus application also significantly influenced biological yield and harvest index. The application of 30 kg P ha^{-1} recorded the highest biological yield (53.84 q ha^{-1}) and harvest index (40.12%), followed by 40 kg P ha^{-1}, whereas the lowest values were observed under 20 kg P ha^{-1}. Adequate phosphorus availability enhanced root development, nutrient uptake, photosynthetic efficiency, and translocation of assimilates, which contributed to increased biomass production and harvest index.

The interaction effect of spacing and phosphorus was significant for both biological yield and harvest index. The treatment combination 40 × 10 cm spacing + 30 kg P ha^{-1} (T_8) recorded the highest biological yield (60.07 q ha^{-1}) and harvest index (41.73%), whereas the lowest values were recorded under 20 × 10 cm spacing + 20 kg P ha^{-1} (T_1). The combined effect of wider spacing and optimum phosphorus application improved biomass production and assimilate partitioning, resulting in higher biological yield and harvest index. These findings are inagreement with the results reported by Kumari *et al*. (2020) [10], Yadav *et al*. (2022), and Sharma *et al*. (2024) [7].

Table 4.7: Effect of different spacing and phosphorus on biological yield and harvest index

	Treatments	Biological yield (qh^{-1})	Harvest index (%)
	Factor I (Spacing)		
1	20 x10 cm	48.79	38.86
2	30 x10 cm	52.30	39.29
3	40x10 cm	54.92	40.29
	F test	S	S
	SEm	0.350	0.210
	CD (5%, 1%)	1.050	0.630
	Factor II (Phosphorus)		
1	Phosphorus 20 kg/ha^{-1}	47.71	38.38
2	Phosphorus 30 kg/ ha^{-1}	54.77	39.86
3	Phosphorus 40 kg/ ha^{-1}	53.54	40.08
	F test	S	S
	SEm	0.350	0.210
	CD (5%, 1%)	1.050	0.630
	Interaction		
	F test	S	S
	SEm	0.12	0.02
	CD (5%, 1%)	0.35	0.061

Economic analysis of Lathyrus (Birsa kulthi-1)

Among all the treatment combinations, T_9 (40 × 10 cm spacing + phosphorus @ 40 kg ha⁻¹) recorded the highest grain yield (24.8 q ha⁻¹), resulting in the maximum gross return of ₹136,400 ha⁻¹ and net profit of ₹58,400 ha⁻¹. The same treatment also recorded the highest benefit-cost ratio (1:2.3), indicating its superior economic viability.

Among the treatments with 30 × 10 cm spacing, T_6 (30 × 10 cm spacing + phosphorus @ 40 kg ha⁻¹) recorded a grain yield of 23.1 q ha⁻¹ with a gross return of ₹127,050 ha⁻¹ and net profit of

₹52,050 ha⁻¹, followed by T_5 (30 × 10 cm spacing + phosphorus @ 30 kg ha⁻¹), which recorded a grain yield of 22.6 q ha⁻¹, gross return of ₹124,300 ha⁻¹ and net profit of ₹48,300 ha⁻¹. Treatment T_4 (30 × 10 cm spacing + phosphorus @ 20 kg ha⁻¹) produced a grain yield of 22.0 q ha⁻¹ and generated a net profit of ₹45,000 ha⁻¹ with a benefit-cost ratio of 1:1.9. under 20 × 10 cm spacing, T_3 (20 × 10 cm spacing + phosphorus @ 40 kg ha⁻¹) recorded a grain yield of 21.5 q ha⁻¹ with a gross return of ₹118,250 ha⁻¹ and net profit of ₹44,250 ha⁻¹. This was followed by T_2 (20 × 10 cm spacing + phosphorus @ 30 kg ha⁻¹), which recorded a grain yield of 20.9 q ha⁻¹ and net profit of ₹42,950 ha⁻¹. The lowest economic returns among the treatment combinations were recorded under T_1 (20 × 10 cm spacing + phosphorus @ 20 kg ha⁻¹), which produced a grain yield of 20.4 q ha⁻¹, gross return of ₹112,200 ha⁻¹ and net profit of ₹42,200 ha⁻¹ with a benefit-cost ratio of 1:1.8.The control treatment (T_{10}) recorded a grain yield of 20.0 q ha⁻¹, gross return of ₹110,000 ha⁻¹ and net profit of ₹42,000 ha⁻¹ with a benefit-cost ratio of 1:1.8, which was lower than most of the treatment combinations. Patel *et al.*, (2019) [18], Verma *et al.*, (2018) and Yadav *et al.*, (2020) [10].

Table 4.8: Economic analysis of Lathyrus (Birsa kulthi-1)

Treatment	Yield (q ha^{-1})	Selling rate (₹ q^{-1})	Gross return (₹ ha^{-1})	Total cost of cultivation (₹ ha^{-1})	Net profit (₹ ha^{-1})	Benefit Cost ratio (B: C)
T1	20.4	5500	112200	70000	42200	01:01.8
T2	20.9	5500	114950	72000	42950	01:01.8
T3	21.5	5500	118250	74000	44250	01:01.8
T4	22.0	5500	121000	76000	45000	01:01.9
T5	22.6	5500	124300	76000	48300	01:02.0
T6	23.1	5500	127050	75000	52050	01:02.1
T7	23.7	5500	130350	76000	54350	01:02.2
T8	24.2	5500	133100	77000	56100	01:02.2
T9	24.8	5500	136400	78000	58400	01:02.3
T10	20.0	5500	110000	68000	42000	01:01.8

Conclusion

The present investigation revealed that spacing and phosphorus levels significantly influenced the growth, yield attributes, yield, and economics of Lathyrus (*Lathyrus sativus* L.) under the agroclimatic conditions of Prayagraj. Among the spacing treatments, 40 × 10 cm spacing produced significantly higher plant height, number of branches per plant, dry matter accumulation, leaf area index, number of pods per plant, grain yield, biological yield, and harvest index compared with 20 × 10 cm and 30 × 10 cm spacing. Similarly, application of 30 kg P ha⁻¹ proved superior in improving growth parameters, yield attributes, grain yield, biological yield, and harvest index. The interaction effect indicated that 40 × 10 cm spacing combined with 30 kg P ha⁻¹ (T_8) recorded the highest values for most growth and yield parameters, including plant height, branches per plant, leaf area index, pods per plant, biological yield, and harvest index. However, the highest grain yield (24.8 q ha⁻¹), gross return (₹136,400 ha⁻¹), net return (₹58,400 ha⁻¹), and benefit-cost ratio (1:2.3) were obtained with 40 × 10 cm spacing + 40 kg P ha⁻¹ (T_9), indicating its superior economic performance.Therefore, it can be concluded that cultivation of Lathyrus at 40 × 10 cm spacing with phosphorus application of 30–40 kg P ha⁻¹ is beneficial for achieving higher productivity and profitability under the North East Plain Zone of Uttar Pradesh. For maximizing economic returns, the treatment combination 40 × 10 cm spacing with 40 kg P ha⁻¹ (T_9) may be recommended to farmers under similar agro-climatic conditions.

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Conflicts of Interest Statement

The authors declare that they have no conflicts of interest to disclose. This research was conducted independently without any financial support, sponsorship, or external funding from any organization or institution.

The authors contributed to the conception and design of the study, conducted the field experiment, collected and analyzed the data, and prepared the manuscript. All authors critically reviewed the manuscript, approved the final version, and agreed to its submission for publication

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