**Optimization of Phosphorus Level on Yield and Quality of Garlic (*Allium sativum* L.) in the Balaghat region of Madhya Pradesh,India**

**ABSTRACT**

The present investigation was conducted during the late winter season of the 2023-24 academic year at the Horticultural Research Farm, School of Agriculture Science, Technology and Research, Sardar Patel University, Balaghat (M.P.). The experiment followed a Randomized Block Design (RBD) with eight treatments, each replicated three times. The experimental findings identified treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha + K @ 50 kg/ha) as the most effective in enhancing growth parameters like maximum plant height at, number of leaves per plant, neck thickness, yield like number of cloves per bulbs, polar diameter of bulb, Bulb yield per plot, and quality Total Soluble Solid of garlic. Furthermore, T4 recorded the highest benefit-cost ratio of 1:3.53, highlighting its economic viability and superior performance over the other treatments.

**Keywords:**Garlic, Phosphorus, Quality, Yield and Benefit cost ratio

**INTRODUCTION**

“Garlic (*Allium sativum* L.) which belongs to the Amaryllidaceae family and subfamily Allioideae, is one of the most aromatic herbaceous annual spices” (Kurian, 1995). “It ranks as the second most widely cultivated spice crop within the genus Allium, second only to onions globally” (Purseglove, 1975). “Characterized by its distinctive pungent aroma, garlic originated in Central Asia and later spread to the Mediterranean region in prehistoric times” (Thompson and Kelly, 1957). “Renowned worldwide as a versatile spice, garlic enhances various culinary preparations, including pickles, chutneys, curry powders, vegetables, and tomato ketchup. Additionally, it is highly valued in Unani and Ayurvedic medicine for treating conditions such as chronic gastrointestinal infections, dysentery, typhoid, cholera, and respiratory illnesses” (Chopra *et al.*, 1958). “Its health benefits are attributed to amino acids, which help reduce cholesterol levels in human blood. Furthermore, garlic clove extracts, rich in allicin and related disulphides, have been shown to lower cholesterol” (Augusti, 1977) “and eliminate waste and harmful free radicals from the body” (Durak *et al.*, 2004).

“In 2021, India ranked second after China in garlic cultivation, with an area of 352.19 thousand hectares and a production of 3207.09 thousand tonnes, achieving an average productivity of 9.106 tonnes per hectare. However, only 2–3% of domestic production was exported. Madhya Pradesh ranked first in garlic production among all Indian states with a production of 2016.23 thousand tonnes, followed by Rajasthan, producing 539.18 thousand tonnes annually” (NHB, 2022). “Declining yields, nutrient use efficiency, soil fertility, and overall productivity have been observed in the region.Phosphorus plays a crucial role as a structural component of cell membranes, chloroplasts, and mitochondria. It is a key constituent of energy molecules such as ADP and ATP, as well as nucleic acids, nucleoproteins, purines, pyrimidines, nucleotides, and various coenzymes. Essential for photosynthesis, cell division, carbohydrate metabolism, energy transformation, and plant respiration, phosphorus also facilitates genetic material transfer and hastens plant maturity. Despite its importance, 93–99% of soil phosphorus exists in insoluble forms, rendering it unavailable for direct plant uptake. Only about a quarter of water-soluble phosphate is taken up by plants in the season of the application and the remaining is converted into insoluble (unavailable) forms” (Jitarwal *et al.*2018)

**MATERIALAND METHODS**

The present investigation was conducted to evaluate the effect of different phosphorus levels on the growth and yield of the garlic variety 'Bhima Shankar. The materials used in this investigation were applied at the Horticulture Research Field, Department of Horticulture, School of Agricultural Science, Technology and Research, Sardar Patel University, Balaghat, (M.P.) during the *Rabi* season of 2023. Balaghat district is located in the south-eastern part of the Satpura Range and in the upper valley of the Wainganga River. It lies between 21°19’ and 22°24’ N latitude, and 79°31’ and 81°30’ E longitude The treatments were T0 (Control), T1 (N @ 100 kg/ha + P @ 40 kg/ha+ K @ 50 kg/ha each), T2 (N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each), T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each), T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each), T5 (N @ 100 kg/ha + P @ 80 kg/ha+ K @ 50 kg/ha each), T6 (N @ 100 kg/ha + P @ 90 kg/ha+ K @ 50 kg/ha each). The height of five randomly selected plants from each plot was measured in cm with help of a 100 cm meter scale from ground level to tip of the shoot at 30, 60 and 90 DAT. The average of plant height of each replication was recorded and subjected to statistical analysis. Number of leaves per plant was counted at 30, 60 and 90 DAT. Neck thickness of ten tagged plants was measured using a vernier caliper at harvest and recorded in centimetres. Total number of cloves was counted from ten randomly selected bulbs to compute the mean number of cloves per bulb. The weight of a single bulb from the tagged plants was taken, averaged and analyzed for further data collection. The total no. of bulbs produced from the plot was calculated in kg yield per plot. The average of a fruits yield per plot was calculated and subjected to statistical analysis. The statistical analysis was conducted using Fisher and Yates (1963).

**RESULTS AND DISCUSSION**

1. **Growth Parameters**

At 30 DAT, maximum plant height was recorded in the treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (28.81 cm) which was statistically at par with treatment T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each), (27.60 cm) and the minimum (21.29 cm) plant height was recorded in T0- control. At 60 DAT, maximum (39.57 cm) plant height was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) which was statistically at par with treatments and followed by the T3 (38.38 cm), T3 (N @ 110 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each), (27.60 cm) (41.48 cm), The minimum (31.69 cm) plant height was recorded in control. At 90 DAT, maximum (73.87 cm) plant height was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) which was statistically at par with treatments T3 (N @ 110 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (72.03 cm). The minimum (63.49 cm) plant height was recorded in control. Garlic treated with N @ 100 kg/ha, P @ 70 kg/ha and K @ 50 kg/ha each shows better plant height due to optimal nutrient availability. Nitrogen promotes vigorous vegetative growth, phosphorus enhances root development and energy transfer, and potassium improves overall plant health and stress resistance, leading to robust growth and increased plant height. Similar findings were concluded by Meena *et al.*, (2018) and Anwar *et al.*, (2024).

At 30 DAT, maximum number of leaves per plant was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (5.85), followed by T3 (N @ 110 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (5.49). The minimum (3.29) number of leaves per plant was recorded in control T0. At 60 DAT, maximum number of leaves per plant was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (7.96), followed by T3 (N @ 110 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (7.53). The minimum (5.72) number of leaves per plant was recorded in control T0. At 90 DAT, maximum number of leaves per plant was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (10.56), followed by T3 (N @ 110 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) 9.65). The minimum (7.77) number of leaves per plant was recorded in control T0.This might be due to the better availability and uptake of plant nutrients, more specifically N, P and K, resulting in better photosynthesis and protein synthesis and the pronounced effect in terms of all the above mentioned growth parameters similar results also given by Similar finding was also reported by Alemu-Degwale *et al.*, (2016), Shiferaw *et al.*, (2018) and Fouda (2020).

The maximum neck thickness was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (7.42 cm), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (7.38 cm). The minimum (4.45 cm) neck thickness was recorded in control. The balance of nutrients from NPK fertilizer when it is reached will have an impact on the hardness of plant tissue so that plants become stronger which might have helped to the translocation of cytokinins as well as more quantity of available phosphorus through the xylem vessels and their accumulation in the axillary buds that would have favoured the plant to enter into reproductive phase. Similar finding was also reported by and Krestini *et al.*, (2020).

1. **Yield parameters**

The maximum number of cloves per bulbs was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (21.60), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (19.38 cm). The minimum (11.55 cm) number of cloves per bulbs was recorded in control. This might be attributed to the increased availability of NPK and water at the critical stages of the crop growth resulting early establishment, vigorous growth and development of plants leading to longer to maximum number of cloves integrated application of fertilizers by Similar results were also obtained by Meena *et al.*, (2018) and Anwar *et al.*, (2024).

The maximum bulb weight (g) was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (22.36 g), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (20.06 g). The minimum (14.19 cm) bulb weight (g) was recorded in control. Reason behind the increase in fresh bulbs weight of garlic due to Phosphorus application could be attributed to easy solubilization effect of released plant nutrient leading to improve nutrient status and water holding capacity of the soil. Similar results were also reported earlier by Alemu-Degwale *et al.*, (2016), Shiferaw *et al.*, (2018) and Fouda (2020).

The maximum polar diameter of bulb (cm) was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (3.20 cm), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (3.09 cm). The minimum (1.82 cm) Polar diameter of Bulb (cm) was recorded in control. “The balance of nutrients from NPK fertilizer when it is reached will have an impact on the hardness of plant tissue so that plants become stronger which might have helped to the translocation of cytokinins as well as more quantity of available phosphorus through the xylem vessels and their accumulation in the axillary buds that would have favoured the plant to enter into reproductive phase” which was also reported by and Eti *et al.*, (2020) and Krestini *et al.*, (2022).

The maximum equatorial diameter of bulb (cm) was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (3.73 cm), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (3.56 cm). The minimum (2.55 cm) equatorial diameter of bulb (cm) was recorded in control. This might have occurred due to increased photosynthetic area and translocation of photosynthates in plants which subsequently accelerated the formation of more number of large sized fruits with more number of seeds per fruits resulting in increase in fruit weight. Similar results were found by Alemu-Degwale *et al.*, (2016), Krestini *al.*, (2020) and Anwar *et al.*, (2024) in garlic.

The maximum bulb yield per plot (kg) was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (1.54 kg), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (1.21 kg). The minimum (0.77 kg) bulb yield per plot (kg) was recorded in control. “This may be due to vigour of plant and a greater number of fruits by the combined application the availability of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) also affect the resistance of garlic plants to the percentage of mortality. The balance of nutrients from NPK fertilizer when it is reached will have an impact on the hardness of plant tissue so that plants become stronger at various levels as compared to sole application of NPK at their respective levels” which were also revealed by Arisha *et al.*, (2017) and Jiterwal *et al.*, (2018).

The maximum total soluble solid was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) (40.64 °Brix), followed by T3 (N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each) (39.31°Brix). The minimum (32.90 °Brix) total soluble solid was recorded in control might have improved the chemical (nutrient status, soil pH) and biological properties of soil by enriching the certain metabolites and vitamins that had provided favourable environment for better growth and development of plant which ultimately increased the synthesis and accumulation into the bulb. The findings get full support with the findings of Turk*et al.*, (2001), Alemu-Degwale *et al.*, (2016) and Meena *et al.*, (2018).

1. **Economic parameter**

Maximum cost of cultivation incurred in treatment T6 (N @ 100 kg/ha + P @ 90 kg/ha+ K @ 50 kg/ha each) with (Rs 305822 per hectare) and the minimum (Rs 277672 per hectare) was recorded in treatment T0 (Control).

Maximum gross returns were recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) with (Rs 1057640 per hectare) followed by T2 (N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each) having Rs 1004120 per hectare and the minimum (Rs 871920 per hectare) was recorded in treatment T0 (Control).

Maximum net returns were recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) with (Rs 758068 per hectare) followed by T2 (N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each) having Rs 710798 per hectare and the minimum (Rs 594248 per hectare) was recorded in treatment T0 (Control).

Highest benefit cost ratio was recorded in treatment T4 (N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each) with 3.53 followed by T2 (N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each) having 3.42 and the minimum (3.14) was recorded in treatment T0 (Control).

**Conclusion**

The current experimental findings revealed that the treatment T4 (N @ 100 kg/ha, P @ 70 kg/ha, and K @ 50 kg/ha) outperformed other treatments regarding growth, yield, and quality of garlic. This treatment resulted in the highest net returns, amounting to ₹758,068 per hectare, and recorded the maximum benefit-cost ratio of 3.53. The application of a microbial consortium alongside NPK fertilizers significantly influenced plant height, growth rate, and garlic yield. Moreover, the incorporation of phosphorus in the recommended proportions demonstrated superior results in terms of plant growth and yield when compared to other treatments under evaluation.

**Disclaimer (Artificial intelligence)**

I hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

**Competing Interests**

Authors have declared that no competing interests exist.

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**Table 1: Effect of different levels of phosphorus on plant height, number of leaves per plant and neck thickness of garlic**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment Symbols** | **Treatment combination** | **Plant height (cm)** | | | **No of leaves per plant** | | | **Neck thickness (cm)** |
|  | | **At 30 DAT** | **At 60 DAT** | **At 90 DAT** | **At 30 DAT** | **At 60 DAT** | **At 90 DAT** |
| **T0** | Control | 21.29 | 31.69 | 63.49 | 3.29 | 5.72 | 7.77 | 4.45 |
| **T1** | N @ 100 kg/ha + P @ 40 kg/ha+ K @ 50 kg/ha each | 25.21 | 33.26 | 64.94 | 3.79 | 5.86 | 7.93 | 5.16 |
| **T2** | N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each | 25.56 | 37.01 | 70.65 | 4.32 | 6.87 | 8.59 | 6.53 |
| **T3** | N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each | 27.60 | 38.38 | 72.03 | 5.49 | 7.53 | 9.65 | 7.38 |
| **T4** | N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each | 28.81 | 39.57 | 73.87 | 5.85 | 7.96 | 10.56 | 7.42 |
| **T5** | N @ 100 kg/ha + P @ 80 kg/ha+ K @ 50 kg/ha each | 26.01 | 37.43 | 71.29 | 5.23 | 7.26 | 9.53 | 6.26 |
| **T6** | N @ 100 kg/ha + P @ 90kg/ha+ K @ 50 kg/ha each | 25.42 | 36.95 | 68.92 | 4.56 | 6.37 | 8.23 | 6.24 |
| **CD0.05** | | **0.39** | **0.36** | **0.77** | **0.10** | **0.17** | **0.20** | **0.27** |
| **SE. m (±)** | | **1.19** | **1.10** | **2.37** | **0.32** | **0.57** | **0.62** | **0.84** |

**Table 2: Effect of different levels of phosphorus on yield and quality parameters in garlic**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment Symbols** | **Treatment combination** | **No of cloves per bulb** | **Bulb weight (g)** | **Polar diameter of bulb (cm)** | **Equatorial diameter of bulb (cm)** | **Bulb yield per plot (kg)** | **TSS [°Brix]** |
| **T0** | Control | 11.54 | 14.19 | 1.82 | 2.56 | 0.77 | 32.90 |
| **T1** | N @ 100 kg/ha + P @ 40 kg/ha+ K @ 50 kg/ha each | 13.96 | 15.92 | 2.20 | 2.76 | 0.96 | 35.14 |
| **T2** | N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each | 17.13 | 19.23 | 2.84 | 3.44 | 1.05 | 36.35 |
| **T3** | N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each | 19.38 | 20.06 | 3.09 | 3.56 | 1.21 | 39.31 |
| **T4** | N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each | 21.61 | 22.36 | 3.20 | 3.73 | 1.54 | 40.64 |
| **T5** | N @ 100 kg/ha + P @ 80 kg/ha+ K @ 50 kg/ha each | 18.08 | 19.78 | 2.62 | 3.44 | 1.23 | 37.38 |
| **T6** | N @ 100 kg/ha + P @ 90kg/ha+ K @ 50 kg/ha each | 16.52 | 16.98 | 2.58 | 3.43 | 1.13 | 36.80 |
| **CD0.05** | | **0.44** | **0.31** | **0.09** | **0.17** | **0.05** | **0.24** |
| **SE. m (±)** | | **1.37** | **0.97** | **0.27** | **0.53** | **0.17** | **0.73** |

**Table 3. Economics as influenced by different treatments applied in garlic**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatment Symbols** | **Treatment combination** | **Cost of cultivation (Rs)** | **Gross return (Rs)** | **Net return (Rs)** | **BC ratio** |
| **T0** | Control | 2,77,672 | 8,71,920 | 5,94,248 | 3.14 |
| **T1** | N @ 100 kg/ha + P @ 40 kg/ha+ K @ 50 kg/ha each | 2,90,172 | 9,15,280 | 6,25,108 | 3.15 |
| **T2** | N @ 100 kg/ha + P @ 50 kg/ha+ K @ 50 kg/ha each | 2,93,322 | 10,04,120 | 7,10,798 | 3.42 |
| **T3** | N @ 100 kg/ha + P @ 60 kg/ha+ K @ 50 kg/ha each | 2,96,422 | 9,97,920 | 7,01,498 | 3.37 |
| **T4** | N @ 100 kg/ha + P @ 70 kg/ha+ K @ 50 kg/ha each | 2,99,572 | 10,57,640 | 7,58,068 | 3.53 |
| **T5** | N @ 100 kg/ha + P @ 80 kg/ha+ K @ 50 kg/ha each | 3,02,672 | 9,68,080 | 6,65,408 | 3.20 |
| **T6** | N @ 100 kg/ha + P @ 90kg/ha+ K @ 50 kg/ha each | 3,05,822 | 9,63,400 | 6,57,578 | 3.15 |