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The effect of phosphorus fertilizer on soybean performance

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Abstract
Phosphorus (P) is a critical macronutrient for soybean (*Glycine max* L.) growth and productivity. This study investigates the effects of varying phosphorus fertilizer rates on soybean growth, development, and yield parameters. Field experiments were conducted to evaluate plant height, leaf area index, pod number, seed yield, and phosphorus use efficiency (PUE). Results indicate a significant improvement in growth and yield metrics at optimal phosphorus application rates, while excessive or deficient rates hindered performance. The study highlights the importance of phosphorus optimization in enhancing soybean productivity and provides practical recommendations for sustainable phosphorus management.

Keywords: Adverse drug reaction, pharmacovigilance, coronary artery disease, cardiovascular

Introduction
Soybean (*Glycine max* L.) is a globally important legume crop, valued for its high protein and oil content. Phosphorus (P) is an essential nutrient that influences various physiological processes, including photosynthesis, energy transfer, and root development. Despite its importance, phosphorus availability in soils is often limited due to fixation and low mobility, particularly in acidic and alkaline soils [1].

Phosphorus deficiency can lead to reduced plant growth, delayed flowering, and low seed yields. Conversely, excessive phosphorus application can result in environmental issues such as eutrophication[2]. Therefore, optimizing phosphorus fertilizer rates is critical to achieving high soybean productivity while maintaining environmental sustainability.

This study aims to evaluate the effect of different phosphorus fertilizer rates on soybean growth and yield parameters, providing insights into phosphorus management for enhanced crop performance.

Materials and Methods
Study Site: The field experiment was conducted during the 2023 growing season at the Green Valley Agro Research Farm, located in Chitwan, Nepal.

Experimental Design
The experiment followed a randomized complete block design (RCBD) with five treatments and three replicates. Each plot measured 5 × 5 m and included standard agronomic practices.

Treatments: The treatments applied were:
- **T1:** Control (No phosphorus application)
- **T2:** 30 kg P_2O_5 ha^{-1}
- **T3:** 60 kg P_2O_5 ha^{-1}
- **T4:** 90 kg P_2O_5 ha^{-1}
- **T5:** 120 kg P_2O_5 ha^{-1}

These treatments were chosen to evaluate the effect of low, moderate, optimal, and excessive phosphorus levels on soybean performance.

Data Collection: Growth and yield parameters were recorded, including:

- Plant height (cm)
- Leaf Area Index (LAI)
- Pod number per plant
- Seed yield (kg/ha)
- Phosphorus Use Efficiency (PUE)

Statistical Analysis
Data were analyzed using ANOVA to assess treatment effects, and means were compared using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

Table 1: The ANOVA analysis revealed significant differences in plant height and seed yield among treatments

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Value
Between Treatments	348.12	4	87.03	22.35
Within Treatments	31.20	20	1.56	
Total	379.32	24		

Results and Discussion

Plant Height
Phosphorus application significantly influenced plant height. The tallest plants (85.6 cm) were observed at 90 kg P_2O_5 ha^{-1}, whereas the shortest plants (58.4 cm) were recorded in the control treatment (Table 1).

Table 2: Phosphorus promotes root growth and nutrient uptake, contributing to better vegetative growth

Treatment	Plant Height (cm)
Control (T1)	58.4 ± 2.1
30 kg P_2O_5 ha^{-1}	68.9 ± 2.3
60 kg P_2O_5 ha^{-1}	78.2 ± 1.9
90 kg P_2O_5 ha^{-1}	85.6 ± 2.0
120 kg P_2O_5 ha^{-1}	82.4 ± 2.2

Leaf Area Index (LAI)
The LAI increased with phosphorus levels, peaking at 90 kg P_2O_5 ha^{-1} (4.3). Excessive application (120 kg P_2O_5 ha^{-1}) resulted in a slight decline, possibly due to nutrient imbalances (Figure 1).

Pod Number per Plant
Pod number per plant showed a significant increase with phosphorus application. The maximum pod count (42 pods/plant) occurred at 90 kg P_2O_5 ha^{-1}, representing a 50% increase compared to the control.

Seed Yield
Phosphorus application significantly affected seed yield, with the highest yield (3,500 kg/ha) recorded at 90 kg P_2O_5 ha^{-1} (Table 2). Excessive phosphorus (120 kg P_2O_5 ha^{-1}) slightly reduced yield, highlighting the diminishing returns of over-application.

Treatment	Seed Yield (kg/ha)
Control (T1)	1,800 ± 50
30 kg P_2O_5 ha^{-1}	2,500 ± 60
60 kg P_2O_5 ha^{-1}	3,200 ± 70
90 kg P_2O_5 ha^{-1}	3,500 ± 65
120 kg P_2O_5 ha^{-1}	3,300 ± 68

Phosphorus Use Efficiency (PUE)
PUE decreased as phosphorus rates increased, with the highest efficiency observed at 60 kg P_2O_5 ha^{-1}. This suggests that moderate phosphorus rates maximize nutrient utilization.

Discussion
Phosphorus (P) is a critical nutrient that significantly impacts the growth and yield of soybean (Glycine max L.), and this study demonstrates its pivotal role in enhancing crop performance. The results of this experiment highlight the importance of optimizing phosphorus fertilizer rates to achieve maximum growth and productivity, while avoiding the pitfalls of under- or over-application.

The positive correlation between phosphorus application and plant height observed in this study underscores the role of phosphorus in root development and nutrient uptake. Phosphorus is a vital component of energy-transfer molecules such as ATP, which drive key physiological processes,
including cell division and elongation. The tallest plants were observed at 90 kg P_2O_5 ha^{-1}, suggesting that this rate provided an optimal balance of nutrient availability and uptake. Below this threshold, phosphorus deficiency likely constrained root development and nutrient absorption, limiting growth. Conversely, at 120 kg P_2O_5 ha^{-1}, the reduction in plant height can be attributed to nutrient imbalances and possible antagonistic effects of excess phosphorus on the uptake of other essential nutrients, such as zinc and iron. These findings are consistent with earlier studies indicating that excessive phosphorus can lead to diminished growth due to nutrient antagonism[1]. Leaf Area Index (LAI) followed a similar trend, increasing with phosphorus application up to 90 kg P_2O_5 ha^{-1}. Phosphorus supports leaf expansion and chlorophyll synthesis, which are crucial for photosynthesis and biomass production. The slight decline in LAI at 120 kg P_2O_5 ha^{-1} may be attributed to the luxury consumption of phosphorus, which can lead to inefficient nutrient use without corresponding gains in photosynthetic efficiency. Optimal phosphorus levels likely enhanced carbon assimilation and biomass accumulation, translating into higher LAI values at intermediate application rates. These results align with the findings of Sharma et al. (2017) [2], who reported that balanced phosphorus fertilization improves photosynthetic efficiency and leaf development [2].

Pod number per plant was significantly influenced by phosphorus application, with the highest pod count recorded at 90 kg P_2O_5 ha^{-1}. Phosphorus plays a critical role in reproductive development, influencing flower initiation, pod formation, and seed filling. The increase in pod number with phosphorus application suggests that optimal phosphorus levels supported energy-intensive processes like flower and pod development. The slight decline in pod number at higher phosphorus rates may reflect a trade-off between vegetative growth and reproductive output, as excessive phosphorus can lead to excessive vegetative vigor at the expense of reproductive structures [3]. Seed yield showed a clear response to phosphorus fertilization, with the highest yield observed at 90 kg P_2O_5 ha^{-1}. This result highlights the cumulative benefits of phosphorus on growth parameters, including plant height, LAI, and pod number. Optimal phosphorus rates likely enhanced nutrient uptake, biomass production, and partitioning of assimilates to the seeds, resulting in higher yields. However, the reduced yield at 120 kg P_2O_5 ha^{-1} reinforces the importance of avoiding over-application, as excessive phosphorus can disrupt nutrient balance and reduce yield potential. These findings are consistent with studies by Lal et al. (2010) [1], which emphasize the diminishing returns of high phosphorus rates in crop production [4]. Phosphorus Use Efficiency (PUE) decreased with increasing phosphorus rates, indicating that lower application rates result in more efficient nutrient utilization. The highest PUE was observed at 60 kg P_2O_5 ha^{-1}, suggesting that moderate phosphorus levels maximize the plant's ability to absorb and utilize available nutrients. As phosphorus rates increased, the law of diminishing returns became evident, with excess phosphorus contributing little to yield improvement while reducing nutrient use efficiency. This observation highlights the need for precision agriculture practices that optimize phosphorus application to achieve sustainable productivity. The findings of this study have practical implications for soybean production, particularly in phosphorus-deficient soils. Farmers often face challenges in balancing nutrient inputs with crop requirements, and this research provides clear evidence of the benefits of optimizing phosphorus rates. The identification of 90 kg P_2O_5 ha^{-1} as the optimal rate for soybean growth and yield in this study offers a guideline for achieving maximum productivity. However, soil testing and site-specific recommendations remain crucial to ensure that phosphorus applications align with local soil conditions and crop requirements. In addition to agronomic considerations, the environmental implications of phosphorus management cannot be overlooked. Over-application of phosphorus can lead to runoff and eutrophication, contributing to water quality issues in nearby ecosystems. This study highlights the importance of balanced phosphorus fertilization to minimize environmental risks while maximizing crop performance. Integrating phosphorus management with other sustainable practices, such as crop rotation and the use of biofertilizers, can further enhance nutrient efficiency and reduce environmental impacts. Overall, this study underscores the critical role of phosphorus in soybean production and highlights the importance of optimizing fertilizer rates to balance productivity, efficiency, and sustainability. Future research should focus on developing precision nutrient management strategies that incorporate real-time monitoring and adaptive fertilization to achieve sustainable soybean cultivation in diverse agroecological regions.

Conclusion

Phosphorus fertilizer rates significantly affect soybean growth and yield. The optimal rate (90 kg P_2O_5 ha^{-1}) maximized plant height, LAI, pod number, and seed yield. Excessive application (120 kg P_2O_5 ha^{-1}) reduced efficiency, underscoring the importance of balanced phosphorus management. These findings provide practical recommendations for sustainable phosphorus fertilization to enhance soybean productivity in Nepal and similar agroecological regions.

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