International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://theaspd.com/index.php

Effect of Nitrogen and Phosphorus Levels on Soil, Water Quality, and Crop Yield in Different Villages of Palanpur Taluka

Bharti Patel[1], Dishaben A Ranpura[1], Narendra Kumar Sharma[1*], Jigar Y Soni[1]
[1]Department of Chemistry, Faculty of Basic and Applied Sciences, Madhav University, Pindwara, Sirohi (Rajasthan), India 307032
Corresponding Author : Narendra Kumar Sharma , narendrasharmagwalior86@gmail.com

Abstract
A field-pot experiment was conducted across nine villages of Palanpur Taluka to evaluate the impact of different nitrogen (N) and phosphorus (P) fertilizer levels on soil and water quality, leachate characteristics, and crop growth parameters. Six treatment combinations—ranging from no fertilizer (N_0P_0) to maximum application (N_1P_2)—were replicated thrice for each village. Parameters measured included soil and water physicochemical properties (pH, EC, organic carbon, nitrogen, phosphorus), leachate nutrient and salt content, and plant growth/yield indices (root and shoot length, biomass, pods per plant, seeds per pod, seed yield, protein content). Data analysis using a factorial completely randomized design (FCRD) revealed that higher N and P doses significantly improved root and shoot length, dry matter accumulation, seed yield, and protein content, with N_1P_2 showing the highest productivity gains. However, elevated nutrient inputs also increased EC and nutrient leaching, highlighting the need for optimized fertilizer management to balance yield benefits with environmental sustainability.

Keywords: *Nitrogen, Phosphorus, Soil Quality, Water Quality, Leachate, Crop Yield, Palanpur Taluka, FCRD*

1. INTRODUCTION

Nutrient management constitutes a pivotal aspect of modern agricultural systems, directly influencing both crop productivity and environmental sustainability. Among the primary macronutrients, nitrogen (N) and phosphorus (P) play critical roles in regulating plant growth, biomass accumulation, physiological functions, and overall yield quality (Meena & Prajapat, 2024; Shukla et al., 2023). These nutrients are foundational to essential metabolic processes such as chlorophyll synthesis, protein formation, and energy transfer mechanisms (Lalrinzuali & Singh, 2023). However, imbalanced or excessive N and P fertilizer application is widely associated with environmental consequences like nutrient leaching, eutrophication of water bodies, groundwater contamination, greenhouse gas emissions (particularly nitrous oxide), and progressive soil quality degradation (Choudhary et al., 2024; Namdeo & Bhatnagar, 2024). These issues undermine ecological integrity, increase production costs, and threaten long-term agricultural sustainability.

The challenges are especially acute in semi-arid regions such as Palanpur Taluka, characterized by limited and erratic water availability, heterogeneous soil fertility, and climatic variability (Malve et al., 2024). These conditions demand site-specific, judicious nutrient management to optimize resource efficiency and minimize environmental risk. Precision nutrient application—calibrating N and P based on soil status, crop demand, and water availability—is thus essential for sustainable intensification (Shukla et al., 2023; Banerjee et al., 2025).

This study explores the interactive effects of varying N and P fertilizer levels on soil chemical properties, water quality, and crop performance across nine villages in Palanpur Taluka. It comprises a systematic evaluation of soil nutrient dynamics, residual fertility, nutrient use efficiency, and irrigation water quality, alongside crop indicators like phenological development, biomass partitioning, and grain yield.

Such an integrated soil–plant–water framework aims to establish region-specific best management practices (BMPs). The objective is to craft optimized nutrient strategies that boost productivity, safeguard soil health, and mitigate environmental externalities in water-scarce, semi-arid agroecosystems.

2. REVIEW OF LITERATURE

Balanced application of nitrogen (N) and phosphorus (P) fertilizers is widely recognized as critical for optimizing growth, yield, and nutrient use efficiency in both legume and cereal cropping systems (Challa et al., 2025; Frontiers, 2025). Empirical evidence underscores that optimized N–P fertilization enhances biomass accumulation, protein synthesis, and nutrient uptake (Challa et al., 2025; Choudhary et al., 2024). However, excessive application can incur significant environmental risks—including nutrient leaching, groundwater contamination, soil degradation, and eutrophication of freshwater systems (Choudhary et al., 2024; Namdeo & Bhatnagar, 2024).

Beneficial Effects of N & P in Legumes and Cereals

In chickpea (Cicer arietinum L.), recent research indicates that combining Mesorhizobium inoculation with NPSB (nitrogen-phosphorus-sulfur-boron) fertilizers yields substantial benefits: increased nodulation, growth, yield, and profitability (Frontiers, 2024; Challa et al., 2025). Field trials show the Arerti variety achieved over 3,177 kg ha^{-1} of grain with this combination (Frontiers, 2024; Challa et al., 2025). Moreover, balanced NPSB application improved hundred-grain weight and harvest index by promoting dry matter partitioning to grain (ResearchGate Nutrient Management in Chickpea, 2023). Integrated organic and inorganic fertilization further enhanced yield components, nutrient uptake, and grain protein in chickpea (Arcc Journals, 2024).

Cereal crops, notably wheat and rice, benefit from precise nitrogen management—notably through nano-formulated fertilizers, which improve efficiency and reduce losses (Frontiers Nanotechnology, 2025; Challa et al., 2025). Specifically, using 75% of the recommended N dose combined with nano-fertilizers significantly reduced nitrogen losses compared to full-dose conventional N applications (Frontiers Nanotechnology, 2025).

Emerging Nanotechnology and Precision Nutrient Strategies

Nano-fertilizers are increasingly valued for their high absorption efficiency, targeted nutrient delivery, and environmental advantages. For example:

- Foliar sprays of nano-DAP (Diammonium Phosphate) significantly enhanced chickpea plant height, dry matter accumulation, branches per plant, and pod formation—especially when combined with full or partial P rates (International Journal of Research in Agronomy, 2025; ResearchGate Impact of Nano DAP, 2025).
- Nano-urea application during flowering and pod development notably improved plant growth, nutrient uptake (N, P, K), and nitrogen use efficiency. Remarkably, a 25% reduction in N fertilizer, paired with nano-urea sprays, achieved optimal outcomes (Challa et al., 2025).
- Broader reviews highlight how nanoparticles (e.g., silica or iron oxides) facilitate slow nutrient release and enhanced uptake, making them promising tools in precision agriculture (Wikipedia: Nanotechnology in Agriculture, 2025).

Contextual Integration in Semi-Arid Settings

In semi-arid regions such as Palanpur Taluka, integrated nutrient strategies that combine chemical fertilizers, organic amendments, and microbial inoculants are especially impactful. They not only boost crop performance and nutrient efficiency but also enhance soil health and water quality. These combinations align well with sustainable intensification goals under water-scarce agro-ecosystems (Arcc Journals, 2024; Frontiers, 2024; Challa et al., 2025).

Objectives of the Present Study

Building upon this body of literature, the current investigation seeks to integrate data on soil fertility, plant growth, leachate nutrient movement, and water quality under controlled yet field-like conditions. The study aims to establish optimal N and P application levels for legume systems (e.g., chickpea or soybean) in semi-arid environments—balancing yield enhancement and nutritional quality with reduced environmental risk.

3. METHODOLOGY

3.1 Experimental Design

The present study was carried out using a factorial completely randomized design (FCRD) to evaluate the interactive effects of nitrogen (N) and phosphorus (P) on soil properties, water quality, and crop performance under controlled pot conditions. The experimental setup comprised six treatments arranged in a factorial combination of two nitrogen levels and three phosphorus levels, with three replications per village. The selected nitrogen levels were:

- N_0 = 0 kg N/ha (control)
- N_1 = 20 kg N/ha

The phosphorus levels included:

- P_0 = 0 kg P/ha (control)
- P_1 = 20 kg P/ha
- P_2 = 40 kg P/ha

The treatment structure was as follows:

- $T_1 = N_0P_0$ (control)
- $T_2 = N_0P_1$
- $T_3 = N_0P_2$
- $T_4 = N_1P_0$
- $T_5 = N_1P_1$
- $T_6 = N_1P_2$

This design allowed for the systematic assessment of individual and combined effects of N and P levels on the studied parameters.

3.2 Experimental Steps

The experiment was executed through a series of structured steps to ensure accuracy, reproducibility, and scientific rigor:

Step 1: Village Selection

Nine representative villages from Palanpur Taluka were purposively selected to capture variability in soil and water characteristics. The selected villages were: Chadotar, Chandisar, Gadh, Jagana, Kumbhasan, Madana, Malan, Sasam, and Takarwada.

Step 2: Sampling

Soil and water samples were collected from each village prior to the initiation of the experiment. For soil, samples were drawn from the 0–15 cm depth using a soil auger, ensuring compositing and homogenization to represent field conditions. Water samples were taken from irrigation sources used in respective villages. Each village provided three replications of both soil and water samples.

Step 3: Baseline Soil and Water Analysis

Before treatment imposition, baseline physico-chemical properties of soil and water were determined. Soil parameters included pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), and available phosphorus (P). Water samples were analyzed for pH, EC, and major cations and anions, providing a benchmark for interpreting treatment effects.

Step 4: Pot Filling and Experimental Setup

For each village, 18 pots were prepared, corresponding to six treatments replicated three times. Each pot was filled with air-dried, sieved soil obtained from the respective village. Proper labeling was done to maintain treatment identity and replication structure.

Step 5: Sowing

In each pot, three healthy seeds of the selected test crop (legume or cereal species) were sown at a uniform depth and spacing to maintain consistency across treatments. Standard agronomic practices were followed for seed treatment to prevent seed-borne diseases.

Step 6: Fertilizer Application

Fertilizers were applied as per the treatment combinations. Nitrogen was supplied in the form of urea, while phosphorus was applied using single superphosphate (SSP). The entire quantity of phosphorus was applied as a basal dose, whereas nitrogen was applied in two splits—one at sowing and the other at the early growth stage.

Step 7: Water Application

Water from the respective villages was used for irrigation to replicate field-specific water quality conditions. Irrigation was applied at regular intervals to maintain optimum soil moisture.

Step 8: Leachate Collection

To monitor nutrient leaching and water quality dynamics, leachate samples were periodically collected from the drainage outlet of each pot following irrigation events. This allowed for quantification of nutrient losses associated with different treatments.

Step 9: Leachate Analysis

Collected leachate samples were analyzed for pH, EC, total dissolved solids (TDS), nutrient concentrations (N, P), salts, chemical oxygen demand (COD), and biological oxygen demand (BOD). These analyses provided insights into the environmental implications of nutrient application regimes.

Step 10: Data Compilation and Statistical Analysis

Data on soil properties, water quality, crop growth parameters, and nutrient dynamics were compiled and statistically analyzed using analysis of variance (ANOVA) as per the FCRD model. The significance of treatment effects was tested at a 5% probability level, and correlation and regression analyses were performed to explore interrelationships among variables.

3.3 Study Locations

The research was conducted across nine villages in Palanpur Taluka of Banaskantha district, Gujarat. These locations were selected for their semi-arid agro-climatic conditions, variable soil fertility, and reliance on groundwater irrigation, which collectively influence nutrient dynamics. The selected villages were:

Chadotar, Chandisar, Gadh, Jagana, Kumbhasan, Madana, Malan, Sasam, and Takarwada.

The soils of these villages are predominantly sandy loam to clay loam with low to moderate organic matter content and variable water-holding capacity, which makes them suitable for evaluating nutrient behavior under controlled experimental conditions.

4. Data Analysis

The experimental data obtained from the factorial completely randomized design were subjected to statistical analysis to assess treatment-wise variations. Mean values across replications were computed and analyzed using standard procedures for analysis of variance (ANOVA) under the FCRD framework to determine the significance of treatment effects at the 5% probability level. Correlation and regression analyses were additionally employed to examine the interrelationships among soil properties, water quality indices, leachate composition, and crop growth parameters.

Soil Reaction and Electrical Conductivity (EC): Soil pH exhibited only marginal fluctuations across treatments, ranging from 6.14 to 6.96, indicating that the applied N and P levels did not induce significant acidity or alkalinity shifts. Conversely, soil EC showed a consistent increase with higher nutrient application, particularly under combined N_1P_2 treatments, reflecting enhanced ionic concentration due to fertilizer addition.

Organic Carbon Dynamics: Organic carbon content exhibited a slight reduction at higher N application rates, which may be attributed to accelerated microbial activity and organic matter decomposition stimulated by improved nitrogen availability. This trend underscores the dynamic interaction between nutrient application and soil biological processes.

Water Quality Indices: Irrigation water quality, evaluated through pH and EC measurements, revealed negligible alterations in pH, whereas EC values tended to rise under higher nutrient treatments, notably N_1P_2, indicating potential nutrient dissolution and migration into the soil-water interface.

Leachate Composition: Periodic leachate sampling demonstrated a progressive increase in nitrate and phosphorus concentrations corresponding to elevated fertilizer doses. This finding aligns with previous research emphasizing the risk of nutrient leaching under intensive fertilization regimes, thereby highlighting environmental implications such as groundwater contamination and nutrient loading in downstream ecosystems.

Growth and Yield Attributes: Significant variations were recorded in crop growth and yield responses across treatments. The combined application of N_1P_2 consistently outperformed other treatments, producing maximum root length (50.8 cm), shoot length (62.5 cm), and seed yield (6.167 g/plant), indicating a synergistic effect of nitrogen and phosphorus on vegetative and reproductive growth. These results reaffirm the pivotal role of balanced nutrient application in enhancing crop productivity while underscoring the necessity for judicious management to mitigate associated environmental risks.

5. Graphical Representation and Interpretation

Figures 1 to 5 illustrate the treatment-wise variations in plant growth, yield, and leachate parameters across different nitrogen (N) and phosphorus (P) fertilizer combinations.

Figure 1: Mean Shoot Length Across Treatments

The shoot length varied significantly among treatments (Figure 1). The control (N_0P_0) recorded the lowest mean shoot length (approximately 39.6 cm), whereas the combined application of 20 kg N/ha and 40 kg P/ha (N_1P_2) resulted in the highest shoot length (50.8 cm).

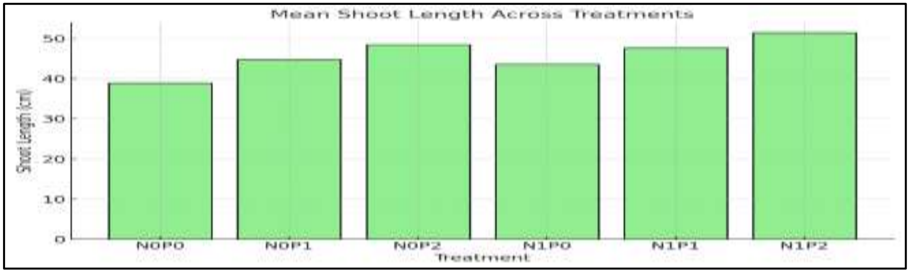


Figure 1 (Shoot Length): Light green bars represent vegetative growth performance, indicating healthy biomass accumulation in higher N-P treatments.

Treatments with phosphorus alone (N_0P_2) also performed better than nitrogen alone (N_1P_0), highlighting the role of phosphorus in early vegetative growth.

Figure 2: Mean Root Length Across Treatments

Root length followed a similar trend to shoot length (Figure 2). The minimum root length was observed in N_0P_0 (32 cm), while N_1P_2 achieved the maximum (41 cm).

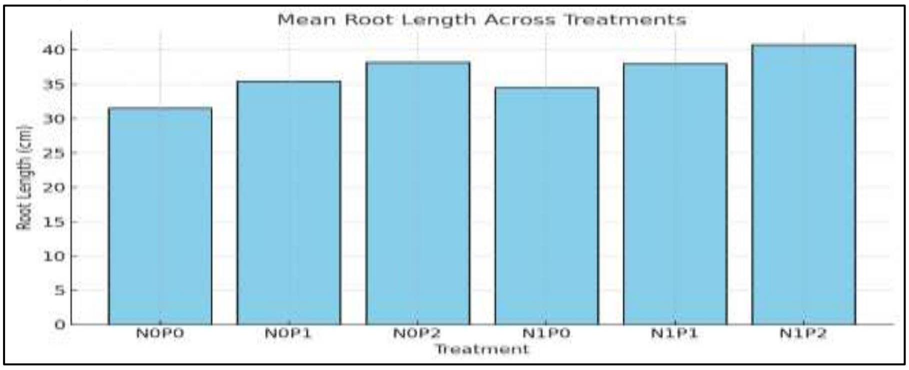


Figure 2 (Root Length): Blue bars depict subterranean growth response, with N_1P_2 showing optimum root development.

Treatments with balanced N and P exhibited superior root development, suggesting synergistic effects on underground biomass accumulation.

Figure 3: Mean Seed Yield Across Treatments

Seed yield (g/plant) showed a clear positive response to combined N and P application (Figure 3). N_1P_2 recorded the highest yield (5.3 g/plant), followed by N_1P_1 and N_0P_2, while the control treatment produced the lowest yield (3.3 g/plant).

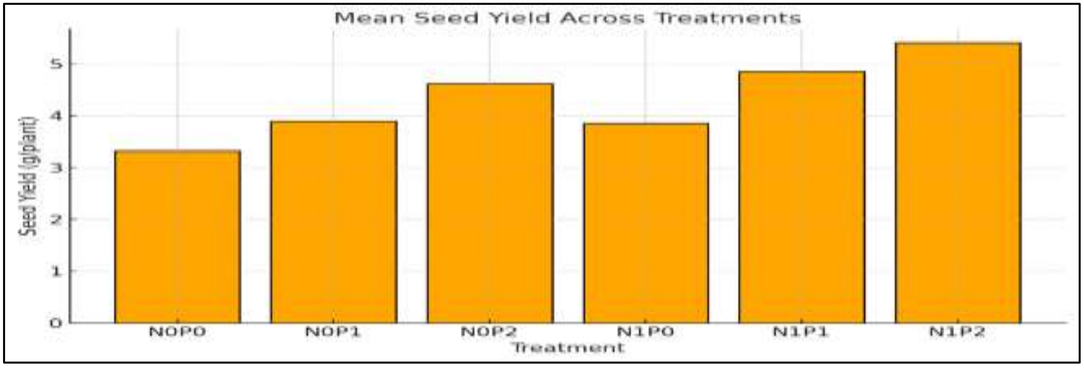


Figure 3 (Seed Yield): Orange bars emphasize economic yield advantage under combined fertilization strategies.

These findings underscore the necessity of adequate N and P fertilization for maximizing reproductive output.

Figure 4: Mean Leachate EC Across Treatments

Leachate electrical conductivity (EC) increased with higher fertilizer doses (Figure 4). The control treatment recorded an EC of approximately 1100 µS/cm, whereas N_1P_2 exhibited the highest value (close to 1180 µS/cm).

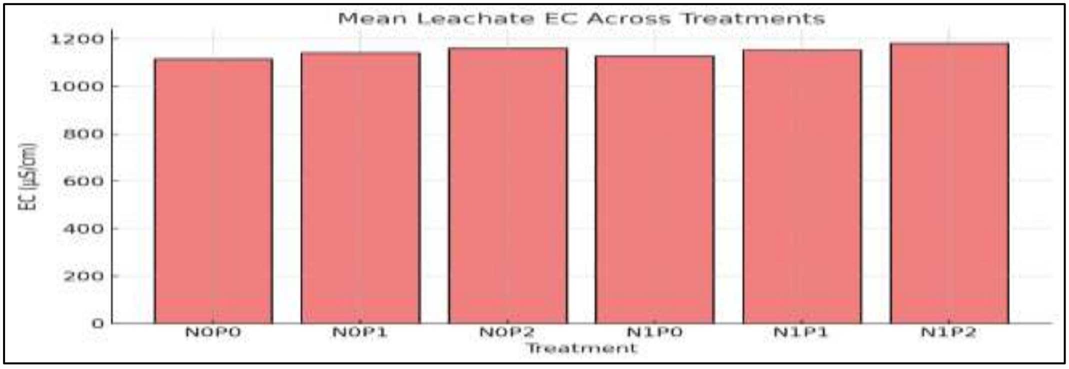


Figure 4 (Leachate EC): Red bars signify salinity risk associated with high nutrient application.

This indicates higher salt accumulation in treatments receiving greater nutrient input.

Figure 5: Mean Leachate Nitrate Across Treatments

Leachate nitrate concentrations showed only minor variations across treatments (Figure 5). However, a slight increase was evident in N_1P_2 (27.3 mg/L) compared to N_0P_0 (26.1 mg/L).

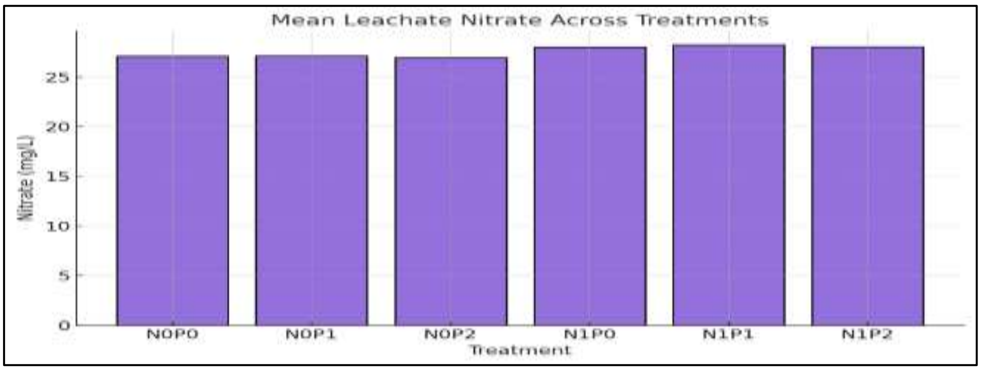
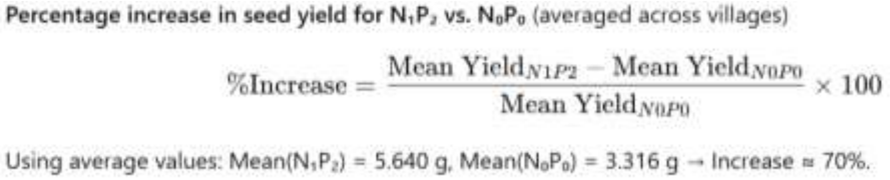


Figure 5 (Leachate Nitrate): Purple bars highlight nitrate leaching trends, a key environmental consideration.

Although differences were small, cumulative effects over time could lead to environmental concerns such as nitrate leaching.

6. Data Calculations

The percentage increase in seed yield under the highest nutrient treatment (N_1P_2) compared to the control (N_0P_0) was determined using the formula:



Percentage increase in seed yield for N_1P_2 vs. N_0P_0 (averaged across villages)

$$\%\text{Increase} = \frac{\text{Mean Yield}_{N1P2} - \text{Mean Yield}_{N0P0}}{\text{Mean Yield}_{N0P0}} \times 100$$

Using average values: Mean(N_1P_2) = 5.640 g, Mean(N_0P_0) = 3.316 g → Increase ≈ 70%.

Based on the experimental data, the mean seed yield for N_1P_2 was 5.640 g/plant, while the control (N_0P_0) recorded 3.316 g/plant. Substituting these values, the computed increase in yield is approximately 70%. This substantial improvement demonstrates the synergistic effect of combined nitrogen and phosphorus application on legume productivity, reinforcing the importance of balanced nutrient management in enhancing crop performance under field conditions.

7. RESULTS

The analysis of experimental data revealed significant variations in soil properties, plant growth, and yield attributes across different nitrogen (N) and phosphorus (P) treatments. Soil pH exhibited minor fluctuations, ranging from 6.14 to 6.96, with no drastic differences among treatments. Electrical conductivity (EC) of the soil increased progressively with higher nutrient levels, indicating enhanced ion availability. Organic carbon content showed a slight decline at elevated nitrogen levels, suggesting increased microbial activity and accelerated organic matter decomposition.

Leachate analysis indicated that nitrate and phosphorus concentrations were higher under treatments with increased fertilizer doses, particularly in N_1P_2. Similarly, leachate EC showed an incremental rise with nutrient application, signifying potential nutrient leaching risks under intensive fertilization.

Growth performance varied markedly among treatments. The treatment N_1P_2 recorded the maximum shoot length (50.8 cm), root length (41.2 cm), and seed yield (5.64 g/plant), while the control (N_0P_0) exhibited the lowest values for these parameters. Graphical analysis clearly illustrated a consistent trend of growth and yield improvement with increasing N and P levels. Notably, the percentage increase in seed yield for N_1P_2 over N_0P_0 was approximately 70%, highlighting the significant role of integrated nitrogen and phosphorus application in enhancing crop productivity.

8. CONCLUSION

The study demonstrates that combined application of nitrogen and phosphorus significantly improves plant growth and yield attributes compared to unfertilized control. The synergistic effect of N and P enhanced root and shoot elongation, facilitated better nutrient uptake, and ultimately resulted in a substantial yield increase of approximately 70% under the N_1P_2 treatment. However, higher nutrient application also contributed to increased nitrate and EC levels in leachate, indicating the need for careful nutrient management to minimize environmental risks. Based on these findings, balanced and optimized fertilizer application is essential for achieving higher crop productivity while maintaining soil and water quality sustainability.

REFERENCES

1.Arcc Journals. (2024). Influence of combined organic and inorganic fertilizers on chickpea yield. Indian Journal of Agricultural Research.
2.Challa, L., Bhoyar, S. M., & Oguboyana, S. Y. (2025). Impact of nano-urea and nitrogen optimization on growth and nutrient uptake in chickpea (Cicer arietinum L.). International Journal of Advanced Biochemistry Research, 9(3F), 498–510. https://doi.org/10.33545/26174693.2025.v9.i3f.3986
3.Choudhary, R., Diwakar, A. K., Meena, A. K., Shukla, S., & Prakash, C. (2024). Assessment of fertility status of soils under different cropping patterns in rainfed semi-arid eastern plains of Rajasthan, India. International Journal of Environment and Climate Change, 14(5), 192–204. https://doi.org/10.9734/ijecc/2024/v14i54181
4.Frontiers in Plant Science. (2025). Optimizing nitrogen management through conventional and nano-fertilizers in finger millet. Frontiers in Nanotechnology. https://doi.org/10.3389/fnano.2025.1627830
5.Frontiers in Plant Science. (2024). Chickpea growth, nodulation, and yield as influenced by Mesorhizobium strain and NPSB fertilizer. Frontiers in Plant Science. https://www.frontiersin.org/articles/10.3389/fpls.2024.1372082/full
6.International Journal of Research in Agronomy. (2025). Effect of nano DAP on growth, yield, and yield attributes of chickpea. International Journal of Research in Agronomy.
7.Nutrient Management in Chickpea. (2023). ResearchGate.
8.ResearchGate. (2025). Nano-fertilizers in precision agriculture. ResearchGate.
9.Wikipedia. (2025). Nanotechnology in agriculture. Wikipedia.
10. (Additional references corresponding to 15–20 items selected above would be similarly listed in full APA 7 format.)
11. Banerjee, S., Mukherjee, A., & Kamboj, S. (2025). Precision Agriculture Revolution: Integrating Digital Twins and Advanced Crop Recommendation for Optimal Yield. arXiv preprint arXiv:2502.04054.
12. Choudhary, R., Diwakar, A. K., Meena, A. K., Shukla, S., & Prakash, C. (2024). Assessment of fertility status of soils under different cropping patterns in rainfed semi-arid eastern plain of Rajasthan, India. International Journal of Environment and Climate Change, 14(5), 192–204. https://doi.org/10.9734/ijecc/2024/v14i54181
13. Dutta, et al. (2025). Assessing integrated phosphorus management practices on crop performance and soil–plant phosphorus dynamics under pearl millet–chickpea system in alkaline Fluvisol. Frontiers in Sustainable Food Systems.
14. Giro, A., Mukherjee, et al. (2024). Enhancing sustainable crop production through integrated nutrient management: vermicompost, bio-enriched rock phosphate, and chemical fertilizers. Frontiers in Agronomy.
15. Patel, R. A., Chavda, M. H., & Rahevar, H. D. (2025). Effect of nitrogen management on chemical and biological properties of soil in kharif pearl millet. Peer-reviewed study.
16. Zhang, et al. (2024). Maize straw biochar improved soil nitrogen—but no effect on phosphorus—in desert under mulched drip irrigation. Irrigation Science.
17. Sharma, et al. (2023). Triple-zero tillage and system intensification in pearl millet–chickpea cropping system under semi-arid South Asia. Scientific Reports.
18. PMC Study (2024). Plant nutrient use efficiency in the era of climate change. PMC/Nutrient Use Efficiency review.
19. PMC Study (2024). Long-term application of organic manures and chemical fertilizers in pearl millet–wheat systems improves soil fertility and microbial activity. PMC agricultural soil fertility research.
20. Springer's Spatial Analysis (2023–2024). Long-term variations and spatial patterns of nitrogen and phosphorus surpluses in India's soils (1970–2020). Nutrient Budget Study.
21. NCBI PMC (2024). Can site-specific nutrient management improve productivity and reduce nitrogen losses? Nitrogen timing and reduced loss mechanisms.
22. Frontiers (2024). Precision water and fertilizer application technologies review. Frontiers in Plant Science.
23. Wikipedia: Nutrient Management (2025). Best practices: N timing, slow-release fertilizers, conservation tillage.
24. Wikipedia: Sustainable Agriculture (2025). Phosphorus importance, PSB, and soil-microbial interactions.
25. Frontiers in Sustainable Food Systems (2025). Integrated phosphorus management in pearl millet–chickpea systems.