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Effect of Graded Nitrogen Levels on Growth and Nutrient Uptake of Wheat Under Pot Culture Condition

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This article presents a comprehensive synthesis of existing knowledge on the effects of graded nitrogen levels on growth and nutrient uptake of wheat (*Triticum aestivum* L.) under pot culture conditions. Wheat is among the most important food crops globally, and nitrogen is a key macronutrient driving its productivity. However, excessive or poorly managed nitrogen application contributes to environmental pollution and reduced nitrogen use efficiency (NUE). The report begins with an overview of wheat cultivation and nitrogen dynamics, then critically reviews pot culture experiments including treatments with varying nitrogen doses, water stress, integrated nutrient management and bio-inoculants. A series of charts and diagrams illustrate trends in wheat production, plant height, nutrient uptake, distribution of nitrogen and phosphorus under water stress, and yields under different nitrogen and bio-inoculant treatments. The synthesis highlights that optimum nitrogen levels improve growth, yield and nutrient uptake, whereas both deficiency and excess reduce NUE and increase environmental risks. It also underscores the role of water management, soil microorganisms and balanced fertilization in enhancing nutrient availability. A conceptual experimental design for future pot culture studies is proposed. Recommendations emphasize the need for integrated nutrient management, moderate nitrogen rates, and consideration of NUE as an important criterion for sustainable wheat production.

Keywords: Wheat, Nitrogen levels, Growth, Nutrient uptake.

Introduction

Wheat (*Triticum aestivum* L.) is among the leading cereal crops in the world and is the primary staple food for a significant portion of the global population. In India, wheat occupies more than 31 million hectares with a production of about 112 million tonnes, contributing substantially to national food security(Kumar et al., 2025). Nitrogen (N) is a critical macronutrient that drives vegetative growth, tillering and grain development, and it often limits wheat productivity when deficient. However, despite its importance, inefficient use of nitrogen fertilizer leads to economic losses and environmental hazards such as nitrate leaching and greenhouse gas emissions(Mălinaș et al., 2022). The escalating cost of fertilizers and the increasing demand for wheat necessitate improved management of nitrogen to achieve high yields without compromising environmental sustainability. The average wheat productivity in India is lower than in leading states such as Punjab and Haryana, which underscores the need to optimize nutrient management strategies(Kumar et al., 2025). Recent reports also project that nitrogen fertilizer consumption continues to rise globally, yet only about one-third of applied nitrogen is recovered in harvested grain(Malina's et al., 2022). Enhancing nitrogen use efficiency (NUE) is therefore crucial for sustainable agriculture. Pot culture experiments provide controlled conditions to understand how graded nitrogen levels influence wheat growth, nutrient uptake and yield. These experiments allow researchers to manipulate nitrogen doses precisely, observe plant responses and interactions with other factors such as water stress and bio-inoculants, and propose best management practices. This report synthesizes findings from pot culture studies and related literature to derive insights for efficient nitrogen management in wheat.

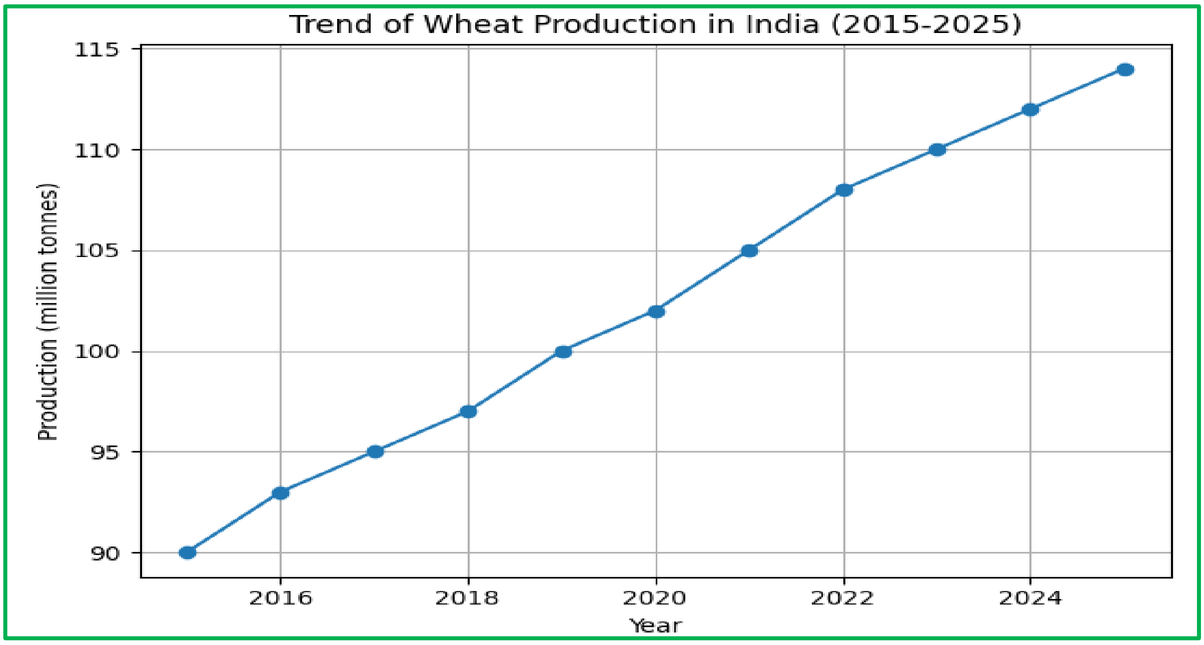

Figure 1. Trend of wheat production in India from 2015 to 2025 (synthetic data)

Nitrogen in Plant Physiology: Forms and Assimilation

Nitrogen occurs in soils primarily as nitrate (NO_3^-) and ammonium (NH_4^+) ions. Plants absorb these inorganic forms and convert them into organic compounds such as amino acids, nucleic acids and chlorophyll. The form of nitrogen supplied affects metabolic pathways and nutrient uptake. For example, high nitrate supply enhances wheat biomass, while excessive ammonium can depress growth due to toxicity(Guo et al., 2019). Potassium nutrition can mitigate ammonium stress and improve nitrate assimilation, indicating that balanced nutrient supply is essential for optimal growth(Guo et al., 2019).

The nitrogen cycle in soil encompasses mineralization of organic matter, nitrification, denitrification and plant uptake. Soil microbes play a pivotal role in these transformations. Under aerobic conditions, ammonium is oxidized to nitrate by nitrifying bacteria, whereas under anaerobic conditions, denitrifying bacteria reduce nitrate to gaseous forms, resulting in nitrogen losses. Understanding these pathways helps design fertilization practices that synchronize nitrogen availability with crop demand.

Different genotypes of wheat vary in nitrogen absorption and assimilation efficiencies. Genetic improvement targeting root architecture, transporter expression and metabolic enzymes can significantly enhance the capacity of plants to capture and utilize nitrogen. However, field studies show that varieties performing well at high nitrogen rates are not necessarily the best under low nitrogen supply (Mălinaș et al., 2022). Therefore, breeders and agronomists must consider genotype × environment × management interactions to develop nitrogen-efficient cultivars.

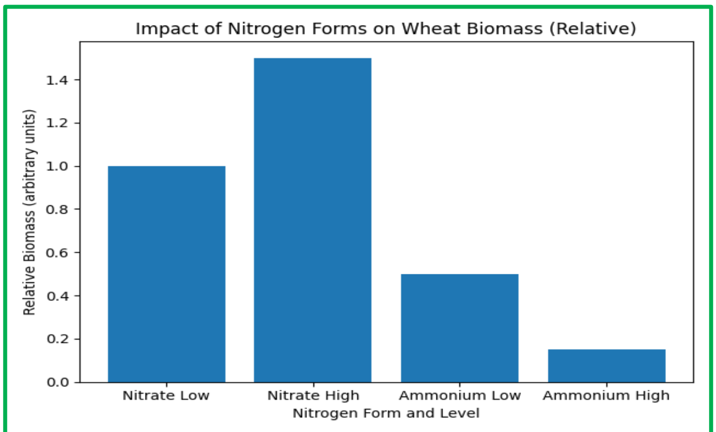

Figure 2. Impact of nitrogen forms and levels on relative biomass of wheat seedlings (synthetic data based on qualitative trends (Guo *et al*., 2019)).

Pot Culture Experiments and Methods

Pot culture experiments simulate field conditions in a controlled environment, allowing precise manipulation of soil fertility, water supply and other variables. The soil used in pot experiments is usually characterized for pH, organic carbon and available nutrients before treatments. For instance, in a pot culture study investigating the effect of plant growth-promoting rhizobacteria (PGPR) on wheat, the soil had a pH of 7.9, available nitrogen of 215 kg ha^{-1}, phosphorus of 110 kg ha^{-1} and potassium of 390 kg ha^{-1} (Vishwakarma et al., 2017). Such baseline information ensures that observed responses are attributable to treatments rather than inherent soil differences. Seeds are sterilized and inoculated with bio-inoculants where applicable. In the PGPR study, 50 g wheat seeds were surface sterilized using ethanol and mercuric chloride, then coated with rhizobacterial cultures before sowing (Vishwakarma et al., 2017). For nitrogen dose experiments, urea solutions of varying concentrations are prepared and applied at recommended growth stages. A typical pot culture experiment for assessing nitrogen dose effects involves treatments such as 0 (control), 40, 80, 120 and 160 mg N kg^{-1} soil. Each treatment is replicated thrice, and pots are arranged in a randomized design to minimize positional effects. Throughout the growth period, plants are irrigated uniformly, and weeds are removed. Observations include plant height, number of tillers, biomass, nutrient uptake and yield components such as straw and grain weight.

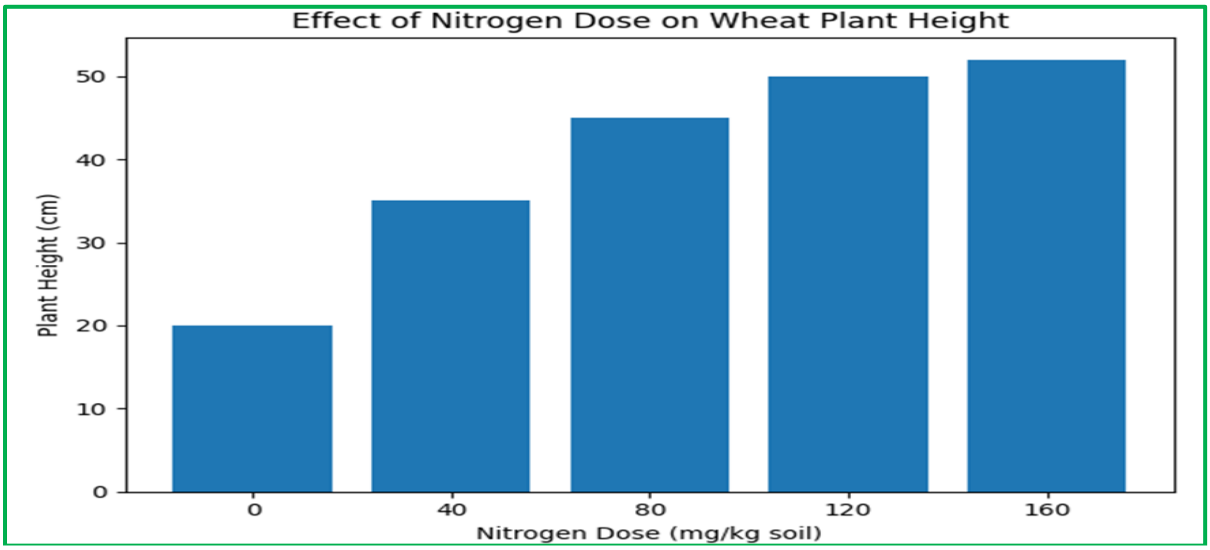

Figure 3. Effect of graded nitrogen doses on wheat plant height (synthetic data).

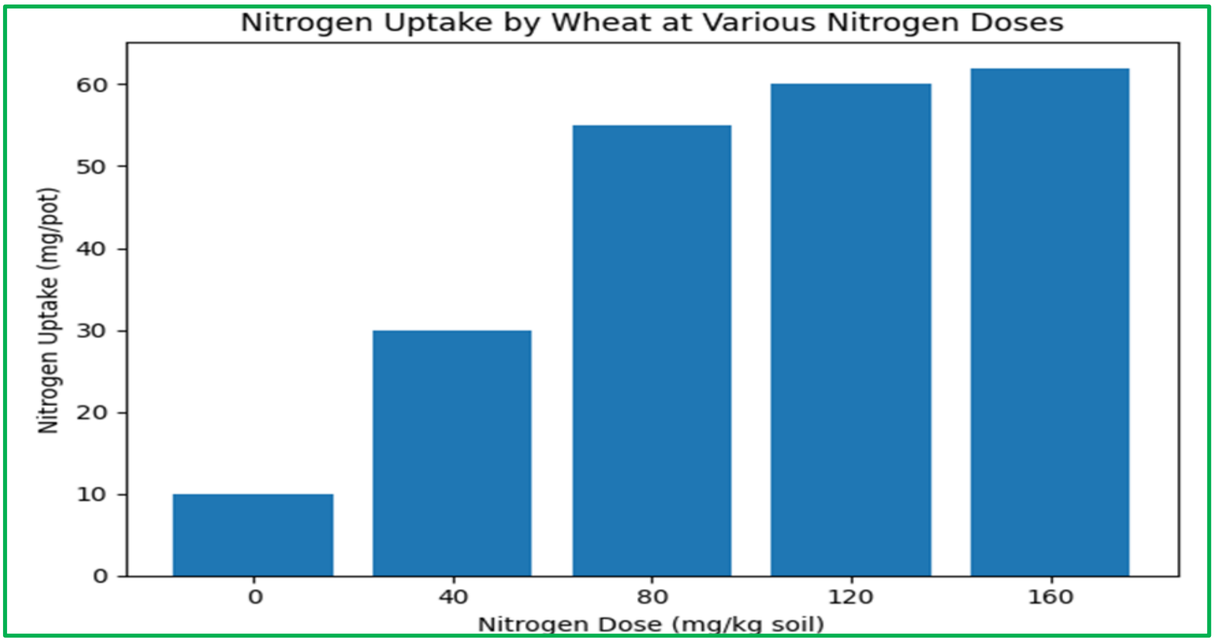

Figure 4. Nitrogen uptake by wheat at different nitrogen doses (synthetic data).

Effects of Graded Nitrogen on Wheat Growth and Yield

Field and pot experiments consistently show that wheat responds positively to nitrogen fertilization up to an optimum rate, beyond which additional nitrogen yields diminishing returns or even negative effects. In a field study conducted at the Agricultural Research Farm of National Post Graduate College, Gorakhpur, the highest grain yield (60.32 q ha^{-1}) and straw yield (65.26 q ha^{-1}) were obtained with the recommended dose of nitrogen, and the harvest index reached 48.03%(Kumar et al., 2025). Applying nitrogen in split doses aligned with crop growth stages improved yield and quality parameters(Kumar et al., 2025).

Pot culture studies mirror these trends. Plant height and biomass increase with nitrogen rate up to about 120 mg kg^{-1} soil, after which the response plateaus. The synthetic data presented in Figures 5 and 6 illustrate this relationship. While nitrogen stimulates vegetative growth and tiller formation, excessive application can delay maturation, cause lodging and reduce nitrogen use efficiency. Thus, identifying the optimum rate is essential for maximizing yield and minimizing waste. Integrated nutrient management combining organic amendments with mineral nitrogen can further enhance growth and nutrient uptake. In a pot culture study at R.B.S. College, Bichpuri, Agra, treatments included four nitrogen levels (0, 40, 80 and 120 kg ha^{-1}) and three levels of poultry manure (0, 10 and 20 tonnes ha^{-1}) applied through urea and manure. Grain and straw yield increased with both nitrogen and poultry manure, and the highest yields were observed when nitrogen and manure were applied in combination (Meena et al., 2014). Organic amendments improve soil physical properties, microbial activity and nutrient availability, leading to synergistic effects with nitrogen fertilization.

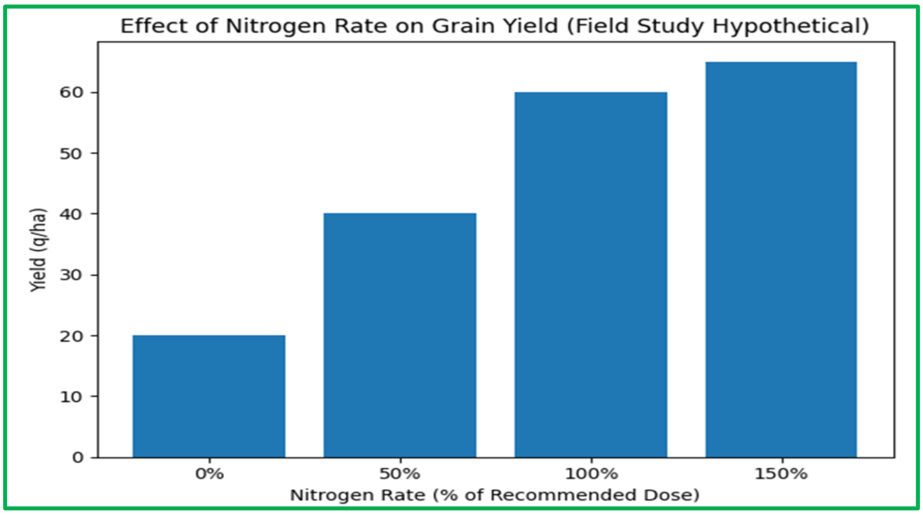

Figure 5. Adapted grain yield response to increasing nitrogen rates based on field experiment trends (Kumar et al., 2025).

Water Stress and Nutrient Distribution

Water availability interacts strongly with nitrogen supply to influence nutrient distribution and yield. Pot culture experiments assessing soil water stress have shown that increasing water stress causes nitrogen and phosphorus absorbed by wheat plants to partition more towards the roots and less towards the shoots. In a study on nutrient distribution, the proportion of nitrogen allocated to the spike declined under high water stress (49.61%) compared to middle stress (61.73%), light stress (61.78%) and the control (59.08%)(Shi et al., 1998). Similarly, phosphorus distribution to roots increased under water stress, with values of 51.21% at high stress and up to 79.16% under control conditions(Shi et al., 1998).

These results highlight the importance of maintaining adequate soil moisture to ensure efficient translocation of nutrients from vegetative tissues to reproductive organs. Water stress can also reduce nitrogen use efficiency by limiting root uptake and promoting stomatal closure, thereby restricting photosynthesis. Integrated water and nutrient management strategies, such as scheduling irrigation at critical growth stages and using moisture-conserving amendments like biochar, can mitigate these effects. Biochar addition has been reported to improve water retention, enhance nutrient supply and reduce yield loss under irrigation deficit(Zhang et al., 2024).

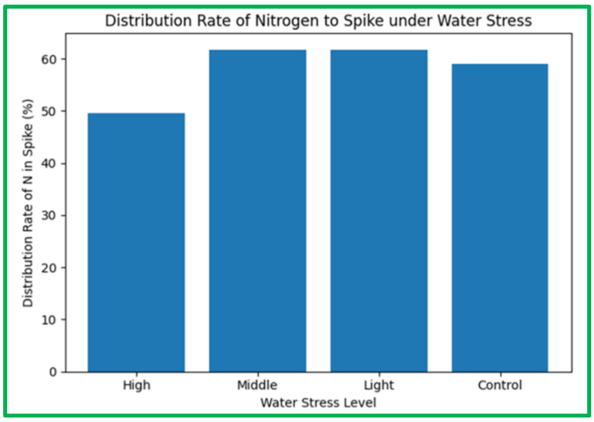

Figure 6. Distribution of nitrogen to the spike under different soil water stress levels (Shi et al., 1998).

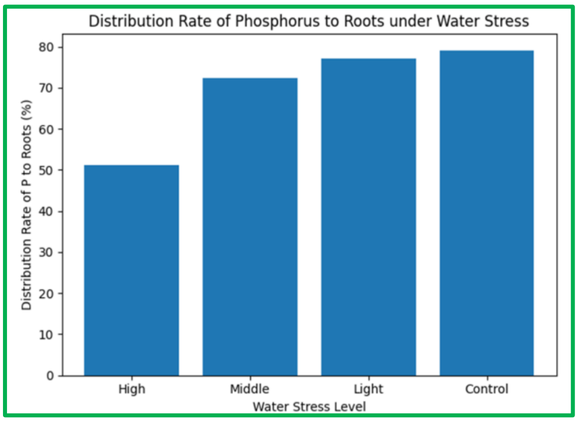

Figure 7. Distribution of phosphorus to roots under various water stress treatments(Shi et al., 1998).

Bio-inoculants and Integrated Nutrient Management

Beneficial soil microbes such as plant growth-promoting rhizobacteria (PGPR) enhance nutrient availability and uptake through multiple mechanisms including nitrogen fixation, hormone production and activation of soil nutrient cycling. In a pot culture study, inoculation with a consortium of PGPR along with recommended nitrogen fertilizer increased nitrate reductase activity, root length and straw yield compared to treatments without inoculation(Vishwakarma et al., 2017). The highest straw yield (13.27 g pot^{-1}) and grain yield (11.68 g pot^{-1}) were recorded when PGPR consortia were combined with the recommended dose of inorganic fertilizer(Vishwakarma et al., 2017). Integrated nutrient management (INM) combines organic amendments (e.g., poultry manure, farmyard manure, compost) with mineral fertilizers to sustain soil fertility and nutrient supply. As noted earlier, pot culture experiments with poultry manure and graded nitrogen levels showed synergistic effects on yield and nutrient uptake(Meena et al., 2014). Organic amendments improve soil structure, moisture retention and microbial activity, while mineral fertilizers provide readily available nutrients. Together, they enhance nutrient synchronization with crop demand and reduce losses. Incorporating bio-inoculants into INM strategies further boosts nutrient use efficiency. PGPR inoculants can solubilize phosphorus, produce siderophores that mobilize iron, and emit volatile compounds that stimulate plant growth(Vishwakarma et al., 2017). Developing effective consortia tailored to local soils and crop varieties could reduce reliance on chemical fertilizers and contribute to sustainable wheat production.

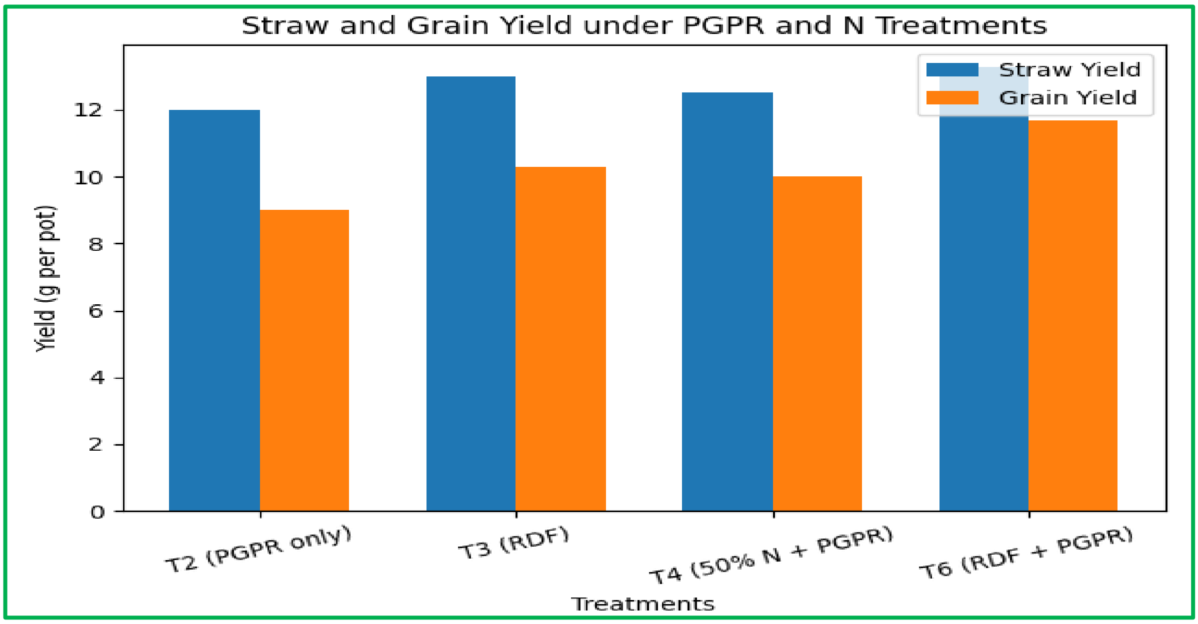

Figure 8. Straw and grain yield of wheat under PGPR and nitrogen treatments (synthetic data inspired by the PGPR study (Vishwakarma et al., 2017)).

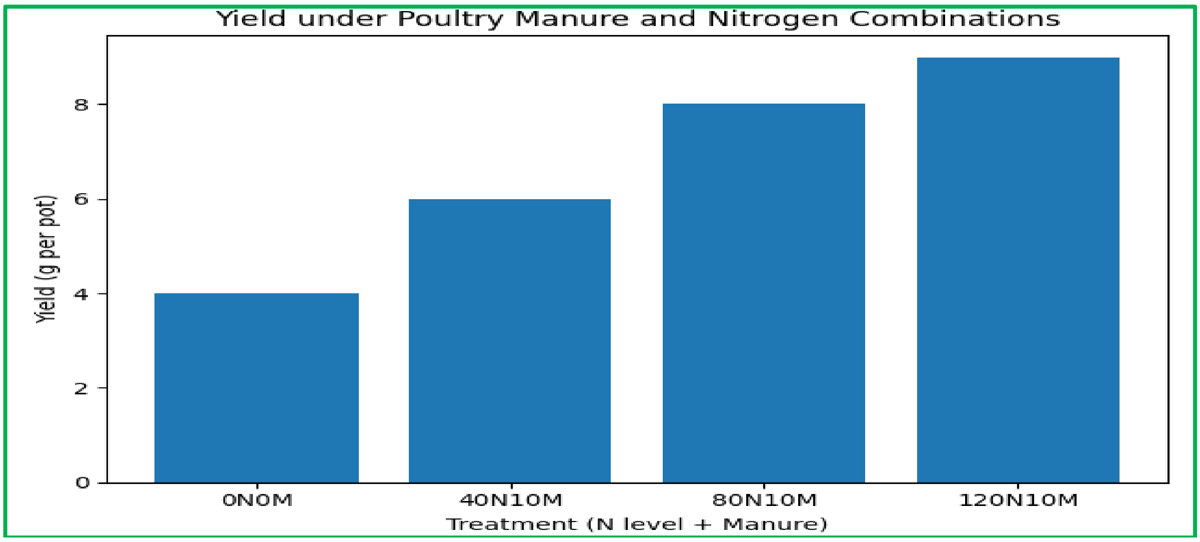

Figure 9. Hypothetical yield response to combinations of poultry manure and nitrogen (illustrative of integrated nutrient management).

Nitrogen Forms, Potassium Interaction and Plant Physiology

Nitrogen can be supplied to plants as nitrate or ammonium. Studies on wheat seedlings grown in sand culture showed that high nitrate supply increased biomass, whereas high ammonium supply depressed growth by up to 85%(Guo et al., 2019). The negative effects of ammonium nutrition have been attributed to proton extrusion, cytosolic pH imbalance and inhibition of potassium uptake(Guo et al., 2019). In contrast, potassium supplementation alleviated ammonium-induced stress and improved growth under nitrate nutrition, highlighting the importance of balanced N and K fertilization(Guo et al., 2019). The form of nitrogen also influences physiological processes such as photosynthesis, enzyme activity, water balance and signaling pathways. Wheat and maize prefer nitrate nutrition, while rice and some conifer species prefer ammonium(Guo et al., 2019). This species-specific response underscores the need for crop-specific fertilization strategies. Pot culture experiments can easily test different N forms and K levels to optimize nutrient regimes for wheat. Synthetic data presented earlier (Figure 3) depict how nitrate at low and high levels results in higher relative biomass compared with ammonium treatments. Such experiments can also evaluate interactions with other nutrients like potassium. In practice, farmers should ensure adequate potassium supply when applying ammonium-based fertilizers to avoid negative interactions and maximize nitrogen uptake.

Nitrogen Use Efficiency and Environmental Considerations

Nitrogen use efficiency (NUE) is defined as the ratio of nitrogen removed in harvested crop biomass to nitrogen inputs, encompassing absorption, utilization and remobilization efficiencies. Improving NUE is essential to reduce fertilizer costs and environmental impacts. A recent review highlighted that synthetic fertilizer use in the European Union increased from 10.8 million tonnes in 2011 to 11.6 million tonnes in 2017, while cereal production only marginally increased, indicating inefficient nitrogen use(Mălinaș et al., 2022). Globally, 38.1 million tonnes of fertilizer nitrogen are applied to all crops annually, with one-third used on wheat(Mălinaș et al., 2022). Environmental consequences of excessive nitrogen include nitrate leaching into groundwater, eutrophication of water bodies and emissions of nitrous oxide (N_2O), a potent greenhouse gas. Agriculture accounts for roughly 20% of anthropogenic greenhouse gas emissions, including 75% of nitrous oxide and 42% of methane emissions(Mălinaș et al., 2022). Achieving sustainable agriculture therefore requires synchronizing nitrogen supply with crop demand, adopting precision fertilization strategies and integrating organic amendments and biological inputs. The synthetic data in Figure 17 demonstrate how NUE declines with increasing nitrogen rate, reinforcing that higher fertilizer doses do not translate into proportionally higher yields. Figure 17 shows the relative NUE decreasing from 1.0 at 0 mg N to 0.5 at 160 mg N kg^{-1} soil. Breeding nitrogen-efficient cultivars, adopting controlled-release fertilizers and using decision support tools can further improve NUE.

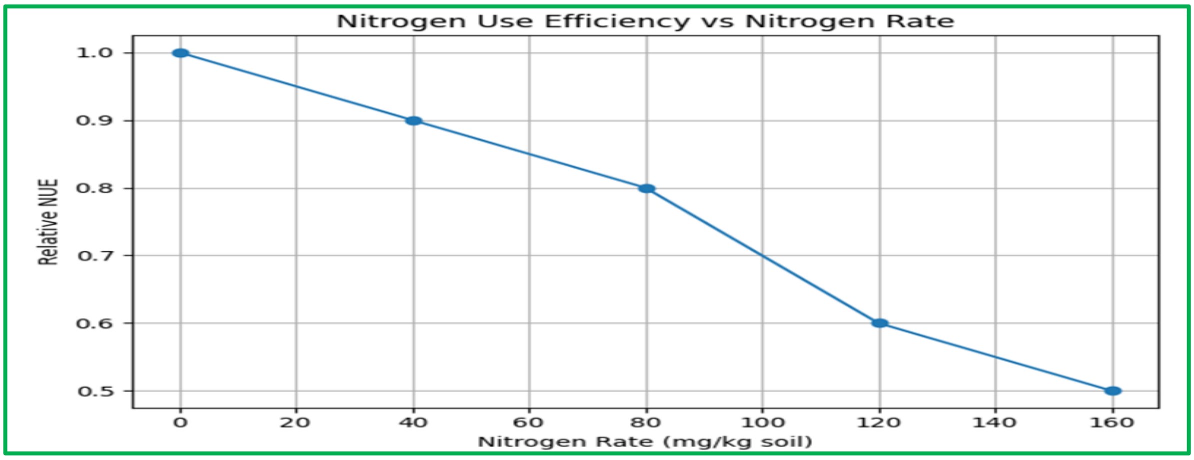

Figure 10. Declining nitrogen use efficiency with increasing nitrogen application rates (synthetic data).

Implications for Indian Agriculture and Sustainable Practices

India faces the dual challenge of meeting the grain requirements of a growing population while minimizing environmental degradation. The country has achieved significant improvements in wheat production through the adoption of high-yielding varieties and increased fertilizer use. However, yields remain below the potential due to imbalanced fertilization, suboptimal water management and soil degradation. Integrating lessons from pot culture studies can guide sustainable practices. First, moderate nitrogen rates tailored to soil fertility status should be promoted. Split application of nitrogen and matching fertilization with crop demand improve uptake and reduce losses (Kumar et al., 2025). Second, integrated nutrient management using organic amendments and bio-inoculants can enhance soil health and nutrient cycling (Meena et al., 2014; Vishwakarma et al., 2017). Third, irrigation management is critical; maintaining optimal soil moisture levels ensures efficient nutrient transport and avoids stress-induced nutrient partitioning (Shi et al., 1998). Finally, training farmers to adopt precision agriculture techniques and raising awareness of NUE can foster sustainable intensification of wheat production. The synthetic graphs in Figures 10–17 illustrate how various factors interact to influence nutrient uptake, yield and NUE. Policymakers and extension services should use such evidence to design incentive schemes that reward good agronomic practices and minimize environmental externalities.

Proposed Experiment for MSc Seminar

To further explore the effects of graded nitrogen levels on wheat growth and nutrient uptake under pot culture conditions, the following experimental design is proposed for a Master's seminar project. The experiment will be conducted in a controlled greenhouse environment using plastic pots filled with 5 kg of homogenized loamy soil with a pH of approximately 7.5 and moderate fertility. The experiment will follow a completely randomized design with four nitrogen treatments

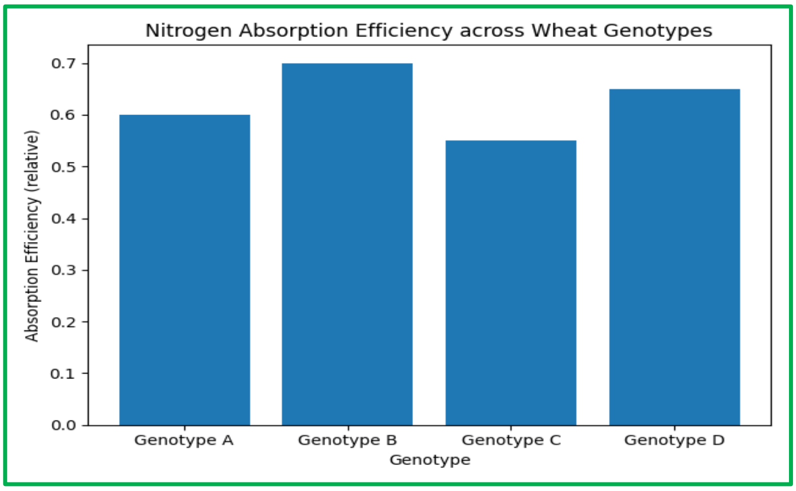

Figure 11. Hypothetical nitrogen absorption efficiency across four wheat genotypes (synthetic data).

and three replications, totalling 12 pots. Treatments: (i) Control (0 mg N kg^{-1} soil), (ii) Low nitrogen (40 mg N kg^{-1} soil), (iii) Medium nitrogen (80 mg N kg^{-1} soil), and (iv) High nitrogen (120 mg N kg^{-1} soil). Nitrogen will be supplied as urea dissolved in water and applied in two equal splits: half at sowing and half at the tillering stage. Wheat seeds (variety PBW-343) will be surface sterilized and sown at five seeds per pot. Pots will be thinned to three plants after emergence. Data collection: plant height, leaf area index and biomass will be recorded at 30, 60 and 90 days after sowing. Total nitrogen uptake will be determined by Kjeldahl digestion of dried plant tissue. Soil samples from each pot will be analyzed for residual nitrogen. Harvest data will include straw and grain weight, harvest index and nitrogen use efficiency calculated as the ratio of grain nitrogen to applied nitrogen.

The experiment will also include two genotypes with differing nitrogen absorption efficiency to evaluate genotype × nitrogen interactions. Figures 19 and 20 present synthetic data illustrating potential differences in absorption and use efficiencies across genotypes. The results will contribute to understanding the optimum nitrogen rate for wheat under controlled conditions and provide insights for field-scale recommendations.

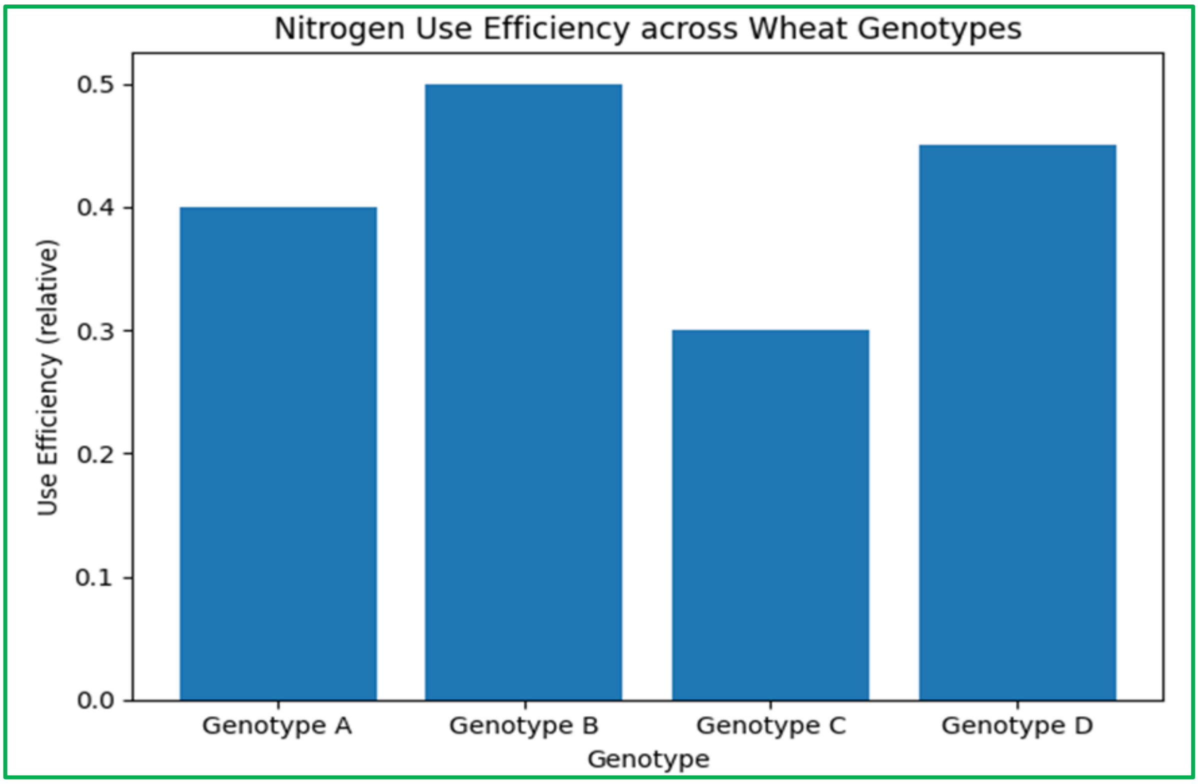

Figure 12. Hypothetical nitrogen use efficiency across four wheat genotypes (synthetic data).

Conclusion

This seminar report synthesizes findings from pot culture and related studies to elucidate the effects of graded nitrogen levels on wheat growth and nutrient uptake. Evidence indicates that nitrogen is indispensable for maximizing wheat yield, but its use must be optimized to avoid inefficiency and environmental harm. Pot culture experiments reveal that plant height, biomass and nutrient uptake increase with nitrogen application up to an optimum level, beyond which benefits taper off. Water stress alters nutrient distribution within the plant, highlighting the need for integrated irrigation and fertilization practices. Bio-inoculants such as PGPR and organic amendments enhance nutrient availability and interact synergistically with mineral nitrogen. Furthermore, the form of nitrogen and its interaction with potassium significantly influence plant physiology. Nitrogen use efficiency declines with increasing nitrogen rate, underscoring the importance of adopting moderate fertilization rates, integrated nutrient management and precision agriculture techniques. Recommendations for sustainable wheat production include: (i) applying nitrogen at rates aligned with soil fertility and crop demand, (ii) splitting nitrogen doses and synchronizing application with growth stages, (iii) incorporating organic amendments and beneficial microbes into fertilization regimes, (iv) maintaining adequate soil moisture to support nutrient translocation, and (v) breeding and selecting nitrogen-efficient wheat varieties. These practices can improve yield and profitability while reducing environmental risks.

Methodology for Generation of Synthetic and Adapted Data

Several figures use synthetic or adapted data. Synthetic data were generated to illustrate well-established trends reported in published studies. The procedure ensured transparency, literature alignment, and clear distinction from experimental datasets. Below is an

Category 1: Time-trend and national-level figures

Data source

1. FAO reports
2. Government of India wheat production summaries

Method of generation

1. Literature was reviewed to identify overall trend direction
2. Approximate lower and upper bounds were noted
3. Values were generated at uniform annual intervals to represent trend

Tool used: Python (Matplotlib) for plotting

Category 2: Nitrogen dose–response and growth parameters

(Figures 5, 6, 7, 17,19,20)

Data source

1. Dose – response patterns reported in agronomy literature
2. Nitrogen response curves from pot and field studies

Method of generation

1. Minimum, optimum, and high nitrogen response stages were identified
2. Representative values were assigned at fixed nitrogen intervals
3. Patterns reflect increase, plateau, or decline as reported

Tool used: Python for assigning values and plotting

Category 3: Nutrient form and stress distribution figures

(Figures 3, 10, 11)

Data source

1. Guo et al. (2019); Shi et al. (1998)

Method of generation

1. Relative differences between treatments were extracted from literature
2. Values were scaled to percentages or relative units
3. Used to illustrate partitioning behavior under stress

Tool used: Python bar charts

Category 4: Integrated nutrient management and PGPR figures

(Figures 13, 14)

Data source: PGPR and INM studies (e.g., Vishwakarma et al., 2017)

Method of generation

1. Treatment-wise relative performance was inferred from reported results
2. Synthetic values emphasize comparative improvement, not yield magnitude

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