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Assessment of Nitrogen and Phosphorus Requirements for Improving Growth and Yield of Pea (Pisum sativum L.)

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Abstract

Nutrient management has prime importance in the production of peas, but poor soil fertility in Pakistan hinders the smooth supply of nutrients, leading to stagnation and a decline in overall Peas productivity. Therefore, this study was conducted to evaluate the effect of nitrogen (N) and phosphorus (P) fertilization on various attributes of pea (*Pisum sativum* L.) under field conditions at Tandojam Horticulture Garden during November 2024. The experiment was laid out in a randomized complete block design (RCBD) with four treatments: level 1 (control), level 2 (N 25 kg ha^{-1}, P 50 kg ha^{-1}), level 3 (N 30 kg ha^{-1}, P 70 kg ha^{-1}), and level 4 (N 30 kg ha^{-1}, P 80 kg ha^{-1}), each replicated three times. Observations were recorded on various vegetative, reproductive and quality attributes. The results showed that level 4 (N 30 kg ha^{-1}, P 80 kg ha^{-1}) significantly enhanced plant height (cm) (63.76 cm), number of branches $plant^{-1}$ (11.22), number of leaves $plant^{-1}$ (58.00), number of flowers (20.44), pods $plant^{-1}$ (18.89), total soluble solids (TSS) (16.77 Brix°), and titratable acidity (TA) (0.22 %). The level 3 (N 30 kg ha^{-1}, P 70 kg ha^{-1}) showed better results for Number of seeds pod^{-1} (7.00) and pod length (8.57 cm). In this treatment, floral initiation (days) was quick (30.55 days). While control showed the highest pH (6.95). The findings indicate that integrated application of nitrogen (30 kg ha^{-1}) and phosphorus (80 kg ha^{-1}) optimizes growth, yield, and pod quality of pea, contributing to sustainable production in nutrient-deficient soils.

Keywords: Macronutrients, Nitrogen, Nutrition, Plant Physiology, Peas.

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Introduction

Peas have great importance in the family of legumes due to their nutritional and chemical composition (Janusauskaite, 2025). They are rich in nutritional abilities like protein, carbohydrates, iron, magnesium, calcium, ascorbic acid, riboflavin, thiamine, and niacin (Sayed and Ouis, 2022). Peas are a widely produced crop in the world, and the major pea-producing countries are Russia, Canada, China, India and the United States (Powers & Thavarajah, 2019). The global pea acreage is approx 7.04 million hectares, and pea seed production is at 10.0 million tons (FAO, 2023). The average yield of peas is about 1.5 tons ha^{-1}; the average of peas yield keeps on increasing in developed countries from 4.0 to 5.0 tons ha^{-1}(Uskutoğlu & Idicut, 2023).

Along with consumption and nutrition, pea production is significant for the environment as well. Despite the fact that there are several hindrances in its production. Among those problems, the huge hindrance is decreased soil fertility and uneven distribution of mineral nutrients in plants such as Nitrogen (N) and Phosphorus (P), which are required to strengthen the root and shoot development (Yeremko et al., 2024). It is necessary for farming structures to be productive, and to remain sustainable for a longer time period, there is a great necessity to get back the nutrients which are lost from the soil (Peoples et al., 1995).

Fertilization is a widely popular method of crop cycle and an essential factor for pea production and its influence on the regulation of biological processes, especially nutrition (Zahir et al., 2003). Nitrogen accelerates vegetative growth of parts of plants (López-Bellido et al., 2005), specifically leaves, which are involved in the production of assimilates that synthesize the biomass of plants, and this happens during the process of photosynthesis (Dordas, 2009). Even though nitrogen is greatly important for the growth cycle of plants, its application in agriculture is fraught with insufficiency. At average rates, crops utilize only 50% of the applied nitrogen from fertilizers, while the remaining percentage is often wasted by various processes, including volatilization, leaching, and denitrification . This range of nitrogen not only hinders crop productivity but also leads to economic crisis for farmers (Fathi, 2022). When nitrogen is lost excessively, the consequences are challenging, including environmental problems dealing with water pollution and greenhouse gas emissions. Pea plants can absorb nitrogen from multiple sources specially from fertilizers and from the reserves of soil, peas tend to fix atmospheric nitrogen in mutual symbiosis with Rhizobium bacteria, which are commonly present in nodules of root and Peas prioritize this method of taking up nitrogen, that happens in organically liberated form and is readily available for metabolic procedues (Malekian et al., 2019). Pea plants possess the potential to completely cover their nitrogen needs from natural biological fixation, but mostly there are three times when they need the mineral nitrogen from the soil itself: when the growth begins, and development starts to occur, before creating a symbiotic relationship with rhizobia, and amidst nodule formation (Jensen & Nielsen, 2003; Wysokinski & Lozak, 2021). The nitrogen source often employed on peas is urea (46% N). In commercial pea cultivation, urea is broadly supplied to fields (Subbaiya et al., 2012), and yield is also improved (Wang & Below, 1996).

Availability of phosphorus is an important factor in the production of peas because legume production requires high phosphorus for the formation and function of nodules (Powers & Thavarajah, 2019). However, above 30% of the world's land lacks the mineral presence of phosphorous which ultimately reduces crop production in that area (Vance et al., 2003). Plants need phosphorus for proper functioning. Sufficient phosphorus application allows legumes to grow a strong and structural root system and provide favourable conditions for the symbiotic fixation of nitrogen to occur (Suleiman & Tran, 2015). Physiologically, peas increase the photosynthetic ability of plants, which ultimately has a positive influence on the morphological features and size of structural elements of plants (e.g., count of branches) and yield (e.g., the count of seeds plant^{-1}), thus producing the increased seed yield of peas in total (Khan et al., 2021). Additionally, phosphorus has an enhancing influence on the growth of plants and biological yield. It can force the roots go deeper and stronger (Sharma, 2002), but it can be sensitive to soil pH. On the other hand, it also induces early ripening of produce (Khan et al., 2021). Despite being the essential nutrients in crop science, nitrogen and phosphorus are not fully appreciated for their role in physiological aspects of the crop growth cycle (Sinclair & Vadez, 2002).

Balanced fertilizer application is the need for getting higher production and superior quality pods. But the imbalanced dose application and improper timing to use chemical fertilizers has negative impact on soil health, thereby affecting overall yield and sustainable production, and also cause environmental pollution. Therefore, there is a need for properly structured use of fertilizers for sustainable production and enriched soil health. This will help to maintain crop yield, improve all the physiochemical and biological characteristics of soil, and increase the potential of applied fertilizers (Fatima, 2018). In this regard, this study was conducted to observe the treatments of N and P, which are suitable for the growth of peas.

Research Objectives and Questions:

1. To evaluate the effect of graded NP levels on vegetative growth of pea.
2. To assess the impact on reproductive development and yield components.
3. To determine the influence on pod quality parameters.

How do different graded levels of nitrogen and phosphorus (NP) affect the vegetative growth parameters of pea plants? What is the impact of graded NP levels on reproductive development and yield components of pea? How do varying NP levels influence pod quality parameters of pea?

Materials and Methods

Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three blocks. Four fertilizer treatments consisting of different levels of nitrogen (N) and phosphorus (P), including a control, were evaluated.

In treatments, the level 1 was considered as control where no nitrogen and phosphorus was applied, level 2 was the dose of 25 kg ha^{-1} nitrogen along with 50 kg ha^{-1} of phosphorous, level 3 dose was Nitrogen at 30 kg ha^{-1} + Phosphorus at 70 kg ha^{-1}, level 4 was dose of Nitrogen at 30 kg ha^{-1} + Phosphorus at 80 kg ha^{-1}.

Nitrogen was applied in two equal splits, with half applied at germination and the remaining half at the vegetative stage. The entire dose of phosphorus was applied at the time of the vegetative stage. Both nutrients were applied through the basal method.

Annexure (A)

Experimental site and area

The experiment was performed on an area of 423 square feet with open field conditions. The soil for seed sowing was prepared to get a fine tilth favourable for the proper establishment of the crop. The soil of the experimental site was silty clay loam in texture. The pH ranged from 6.2 to 6.8. While nitrogen content was low, 0.03–0.05% and phosphorus ranged from 6–10 mg kg^{-1}. The soil had low natural organic matter content, approximately 0.6–0.8%.

Field preparation

The field is deeply ploughed, followed by harrowing and levelling to ensure appropriate pulverization of soil. Post seed sowing and germination, all field practices, such as irrigation, weeding, and plant protection measures, were performed uniformly for all treatments throughout the crop growing period to reduce error in the experiment.

Seed sowing

The seeds of the supreme (EP-190B) cultivar were used. Seeds were soaked in water overnight and then dried before sowing. Seeds were sown on ridges at plant to plant distance of 8 cm. Light irrigation was done immediately post-sowing to facilitate seed germination.

Observations recorded

Random plants were observed for different parameters in each experimental unit throughout the crop growth cycle. Height was measured in centimetres (cm) from the bottom to the apical tip of the plant at the flowering stage. The leaf and branch count was done manually from all fully expanded leaves and branches present on the plant. Yield-contributing parameters were recorded at maturity. Floral initiation was observed as the number of days taken by the seed from sowing until the first flower appearance on each plant, while the total number of flowers per plant was counted during the peak flowering period. The number of pods per plant was counted by recording all pods formed on each selected plant. The seed pod^{-1} was determined by counting seeds from random pods, and the mean value was calculated.

Pod characteristics were also assessed. Pod length was measured in centimetres using a measuring scale from one end of the pod to the other, and average pod length was calculated. The pH was measured using a calibrated digital pH meter. Total soluble solids (TSS) were determined using a refractometer and expressed as °Brix. Titratable acidity was estimated by the titration method.

Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using Statistix software version 8.1**.** The mean values then went through the Least Significant Difference (LSD) test at 5% probability level to observe significant differences in treatments.

Results

The application of different Nitrogen and Phosphorous treatments significantly influenced vegetative growth, reproductive attributes, and quality parameters of garden pea (Figures 1-11). Prominent treatment-wise trends were observed across most parameters, indicating a strong response of pea plants to increasing NP levels.

The results regarding vegetative parameters exhibited that Plant height, number of branches, and number of leaves (Fig. 1-3) showed a progressive increase with increasing treatment level. The maximum plant height (63.76 cm) was observed in level 4 when Nitrogen and phosphorus were applied at 30 kg ha^{-1} + 80 kg ha^{-1}, respectively (fig. 1). Whereas, the minimum plant height (39.99 cm) was recorded under the control treatment. Similarly, number of branches increased from 4.22 in control and level 2 (Nitrogen at 25 kg ha⁻¹ + Phosphorus at 50 kg ha⁻¹) to 11.22 in level 4 (Nitrogen at 30 kg ha⁻¹ + Phosphorus at 80 kg ha⁻¹), indicating a lateral growth due to increased nutrient availability (fig. 2). The number of leaves followed a similar trend (fig. 3), with the highest leaf count recorded in level 3 (Nitrogen at 30 kg ha⁻¹ + Phosphorus at 70 kg ha⁻¹) (58), while the lowest result was observed in control (32.78). This positive vegetative growth trend suggests that higher nitrogen and phosphorus supply increases photosynthetic area on the surface and overall vigour of the plant.

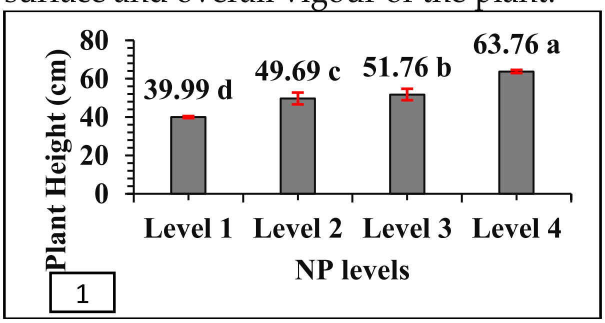

Figure 1: The influence of different levels of Nitrogen and Phosphorous on pea plant height (cm).

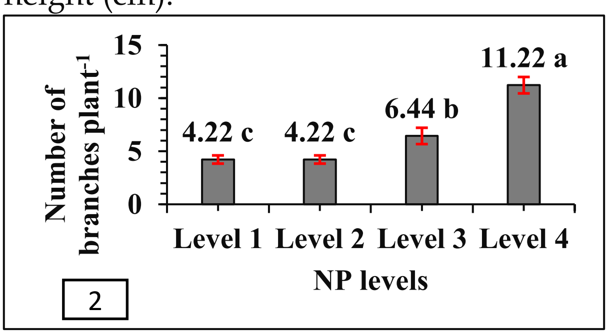

Figure 2: The influence of different levels of Nitrogen and Phosphorus on the number of branches and leaves of Plant-1 of Peas

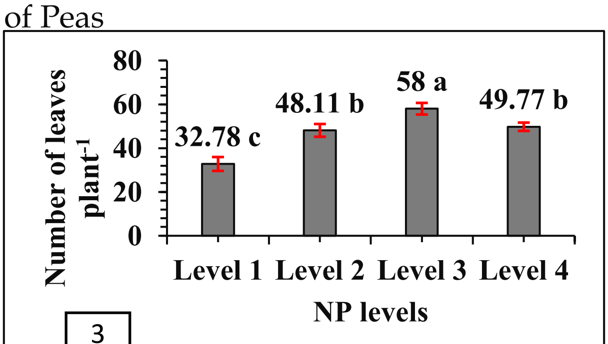

Figure 3: The influence of different levels of Nitrogen and Phosphorus on the number of branches and leaves of Plant-1 of Peas

The effect of nutrients on the floral aspects showed that days to flowering were markedly reduced with increasing NP levels. The seeds in the control treatment took the maximum number of days to flowering (54.11), whereas the earliest flowering was observed in level 3 (30.56 days) (fig.4). This reduction in flowering time under higher NP treatments indicates accelerated crop development and earlier reproductive onset. While the number of flowers planted⁻¹ was highest in level 4 (Nitrogen at 30 kg ha⁻¹ + Phosphorus at 80 kg ha⁻¹) (20.44) and lowest (10) in (control), showing better reproductive efficiency under higher fertilization doses (fig. 5).

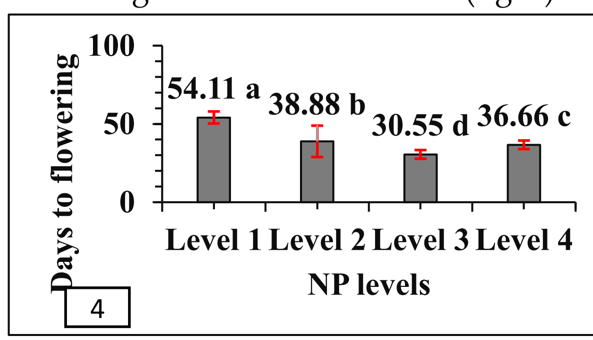

Figure 4: The influence of different levels of Nitrogen and Phosphorus on the floral initiation (days), number of flowers initiated (days), and number of flowers of Peas

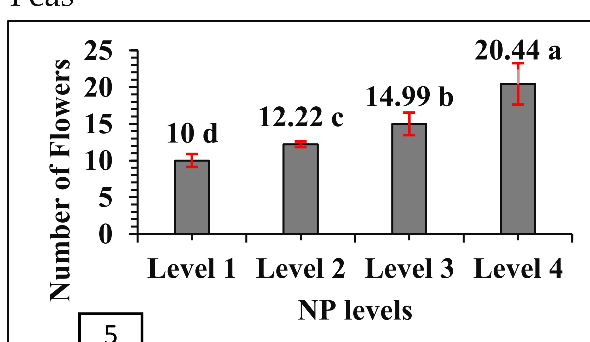

Figure 5: The influence of different levels of Nitrogen and Phosphorus on the floral

initiation (days) and the number of flowers of Peas

Yield-related traits (Fig. 6-8) responded positively to NP treatments. The number of pods per plant^{-1} (Fig. 6) increased steadily from 8.00 in the control to 18.89 in level 4 (Nitrogen at 30 kg ha^{-1} + Phosphorus at 80 kg ha^{-1}), representing more than a twofold increase over the control. Contrastingly, the number of seeds per pod^{-1} (Fig. 7) showed a different response pattern, with the highest value recorded in level 3 (7.00), followed by level 4 (4.78). This suggests that while higher NP enhanced pod formation, an optimum nutrient level (level 3) favoured better seed set within pods. Pod length also increased significantly, reaching a maximum in level 3 of NP (8.57 cm), compared to the shortest pods in the control (4.50 cm) (fig. 8), reflecting improved assimilate translocation under optimal nutrient supply.

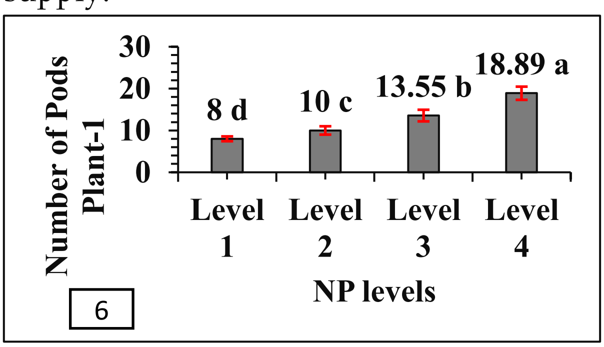

Figure 6: The influence of different levels of Nitrogen and Phosphorus on the pod count and seeds pod^{-1}

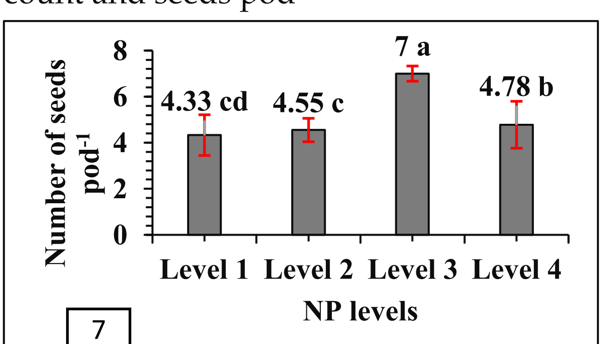

Figure 7: The influence of different levels of Nitrogen and Phosphorus on the pod count and seeds pod^{-1}

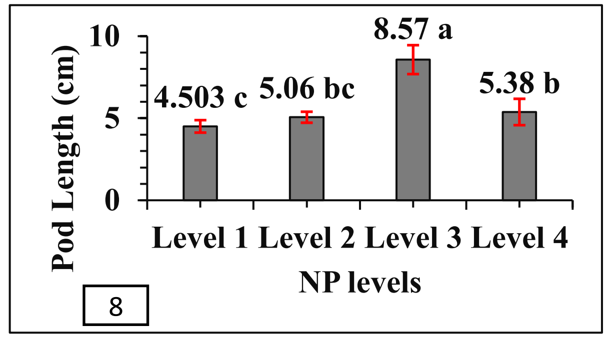

Figure 8: The influence of different levels of Nitrogen and Phosphorous on the length of the pod

Among the quality attributes (Fig 9-11), pH decreased with increasing treatment level, declining from 6.95 in the control to 5.79 in level 4 of NP, suggesting increased organic acid accumulation in pods. This change in pH is indicative of improved metabolic activity (fig. 9). Unlike pH, the total soluble solids and titratable acidity improved significantly with increasing NP levels. Titratable acidity increased from 0.077% in the control to 0.225% in level 4 of NP, reflecting higher organic acid content in pods (fig. 10). TSS increased from 10.22 °Brix in the control to 16.78 °Brix in level 4 of NP, indicating enhanced sugar accumulation and better taste quality (fig. 11).

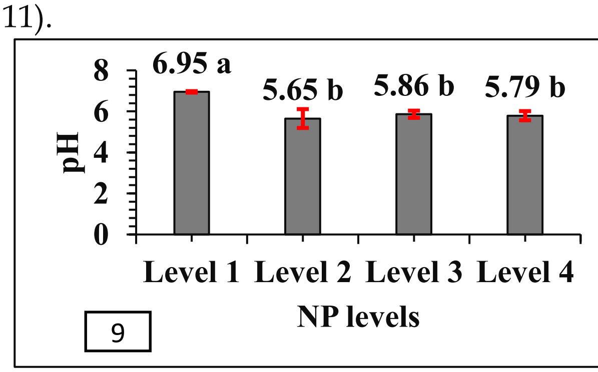

Figure 9: The influence of different levels of Nitrogen and Phosphorus on the pH and Titratable Acidity of Peas

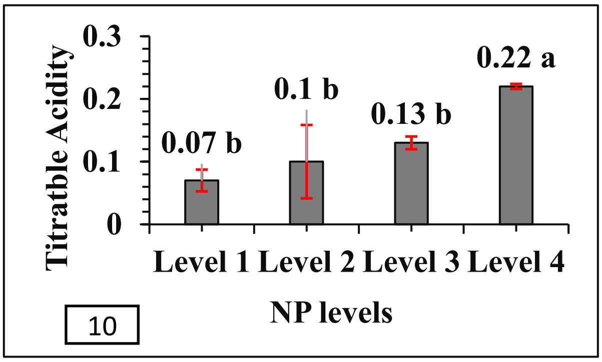

Figure 10: The influence of different levels of Nitrogen and Phosphorus on the pH and Titratable Acidity of Peas

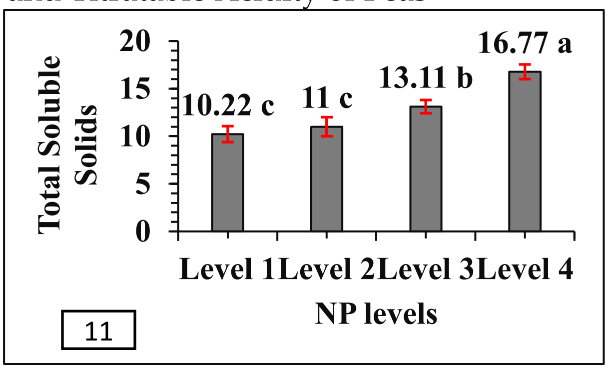

Figure 11: The influence of different levels of Nitrogen and Phosphorus on the Total Soluble Solids of Peas

Discussion

Commercial production of peas is often hindered by a deficiency of essential macronutrients like nitrogen and phosphorus in the soil (White & Brown, 2010). In this study, nitrogen and phosphorus were applied to the plants at different doses.

The results showed that the maximum level of both nutrients showed a prominent positive influence on the vegetative attributes of pea plants, as evidenced by pronounced increases in plant height, number of branches and leaves plant^{-1}. The plant height was highest when Nitrogen at 30 kg ha^{-1} + Phosphorus at 80 kg ha^{-1} was applied. Achakzai (2012) observed similar results regarding plant height when nitrogenous fertilizer was applied in maximum quantity. Study of Khan et al. (2019) exhibited the highest plant height (51.24 cm) upon application of the highest dose of nitrogen, while phosphorus at 80 kg ha^{-1}. Similarly, Uddin et al. (2023) noticed that the maximum quantity of nitrogen and phosphorus showed the highest plant height. According to Choudhary et al. (2024), nitrogen and phosphorus application significantly improved plant height (56.9 cm). It is an absolute fact that nitrogen and phosphorus are the nutrients required in sufficient amounts in available form for the growth of plants (Marschner, 2012). Phosphorus also enhances the availability of nitrogen, which improves the division of cells, leading to taller plants (Mandloi et al., 2020).

Aligning with the results of the current study, Bunker et al. (2022) observed that applying 20 kg ha^{-1} N + 40 kg ha^{-1} P enhanced vegetative parameters in pea plants. According to Choudhary et al. (2024), nitrogen and phosphorus application greatly improved vegetative parameters of pea, for instance maximum number of branches plant^{-1} (12.1), and the number of leaves plant^{-1}. Further, these findings are similar to the results of Singh et al. (2005) and Mathur et al. (2008), where vegetative growth maximized in pea with the incorporation of nitrogen and phosphorus. The major reason for this response is that the adequate supply of nitrogen increases photosynthetic rates and eventually stimulates plant growth (Wang et al., 2023). The lateral buds differentiate into branches, leading to broader canopy architecture and vegetative growth expansion under rigorous phosphatic activity (Aryal et al., 2021). The highest dose enhanced vegetative attributes because lower levels can limit the production of chlorophyll, leading to restricted expansion of leaves, branching and stem growth.

Plants treated with a level 3 N 30 kg ha^{-1}, P 70 kg ha^{-1} dose initiated early flowering, level 4 N 30 kg ha^{-1}, P 80 kg ha^{-1} produced a larger number of flowers. Early flowering in level 3 indicates that it is the optimum level, which is enough for the pea plant to initiate flowering, while a larger number of flowers in level 4 vindicates that, because of a high dose of fertilizer, vigorous vegetative growth is observed, leading to more vegetative biomass for producing more flowers. These findings are closely related to the results observed by Kumar (2011). Similarly, Fatima (2018) recorded minimum days to flowering with the application of $N_{30}P_{50}K_{50}S_{10}$ kg ha^{-1}; these observations support the current study. It is observed that raising nitrogen doses enhances vegetative growth and that enhanced vegetative development positively influences flower formation (Küçükyumuk & Küçükyumuk, 2025). Optimum phosphorus doses regulate flowering by linking with plant hormonal pathways (Mohammed et al., 2018).

The results regarding number of pods $plant^{-1}$, number of seeds pod^{-1} and pod length (cm) of this study evidenced that these parameters maximized with increasing dose of minerals fertilizers, however, number of seeds pod^{-1} and pod length (cm) were maximum in level 3 (N 30 kg ha^{-1} + P 70 kg ha^{-1}) contrasting to number of pods $plant^{-1}$ which showed highest results in Level 4 (N 30 kg ha^{-1} + P 80 kg ha^{-1}), too much higher level of fertilizers like phosphorous may divert the cycle to vegetative growth solely rather than reproductive growth. Further, the positive influence of fertilization on the yielding attributes of wheat was also observed by Badr and Fayed (2020). Study of Khan et al. (2021) showed that plants treated with 90 kg ha^{-1} P resulted in 16.43 pods $plant^{-1}$, which is near-perfect to the result of this study. Another study aligning with the results of this study showed that the number of fresh pod $plant^{-1}$ (20.65) was observed when a 100+60+40 kg NPK ha^{-1} dose was applied (Achakzai & Banqulzai, 2006). Rohith et al. (2020) showed that maximum doses of nitrogen and phosphorus produce a larger number of pods and seeds per pod^{-1}. Fatima (2018) also found similar outcomes regarding the number of pods per $plant^{-1}$, the number of seeds per pod^{-1} and pod length. High-yielding results are observed because of the increased photosynthetic activity (Poorter et al., 2012). At the same time, additional nutrition of the plant with nitrogen during the growing season increases the vegetative growth of the plant (Laghari et al., 2016). Increased pods in plants with phosphorus application may result in pronounced plant growth, consequently enhancing the pods in plants (Hussen and Yirga, 2013). However, the dose of phosphorus when applied in excess of the optimum level has a negative effect on pod development because it can lead to the deactivation of the function of other minerals present in the plant for the growth cycle (Ali et al., 2014). (N 30 kg ha^{-1} + P 70 kg ha^{-1}) Achakzai and Banqulzai (2006) expressed that pod length in pea plants increases with increasing dose of nitrogen fertilization, showing a directly proportional relationship. Khan et al. (2021) showed that, similar to the current study, pod length 9.53 cm was observed with 90 kg ha^{-1}. Achakzai and Banqulzai (2006) expressed a 9.06 cm length of pod with 100+60+40 kg NPK ha^{-1} dose; this result is similar to the current study.

In the current study, pH, total soluble solids, and titratable acidity of pea seeds were evaluated, and the obtained results were aligned with earlier findings by Arif et al. (2020) and Soniya et al. (2025). In this study N 30 kg ha^{-1}, P 80 kg ha^{-1} showed optimum results for pH 5.79, while in control highest pH value was observed, it is because when nitrogen is applied in the urea forms, it acidifies the soil through the process of nitrification, in which hydrogen ions (H^+) are released into the soil, hence, lowering the pH. Phosphorus fertilizers increase the acidification by inoculating the acidic residues and enhancing microbial activity in the rhizosphere. Increasing of total soluble solids is the response of adequate application of vital macronutrients, for instance, nitrogen and phosphorus, which improves fruit quality by making desirable changes in enzymes during the growth and development of the plant (Rani et al., 2017; Waghmare et al., 2018b). Sharma et al. (2013) found increased TSS in the guava and sweet orange cv. Mosambi.

Titratable acidity expressed a similar trend. The ratio of TSS to TA is a general assessing index that indicates whether a balance between sweetness and acidity is maintained or lowered; the highest results indicate enhanced fruit taste (Khamis et al., 2017). Similar results were observed by Gill et al. (2013) in pomegranate. It is widely stated that leguminous crops respond more to fertilization than to any other factor (Li et al., 2011). N 30 kg ha^{-1}, P 80 kg ha^{-1} showed maximum results because N+P enhances the metabolism of energy and translocation of sugars and organic acids to pods and induces high carbohydrate production Teka, 2013; Tran et al., 2017. Consequently, TSS and titratable acidity both increased under N 30 + P 80 as compared to other treatments. Application of nitrogen and phosphorus increases photosynthetic potential, and biosynthesis of sugars, higher sugar accumulation is observed in pods and TSS, which simultaneaously effect organic acid metabolism and dilution, leading to altered titratable acidity and pH. Moderate NP application increases C: N balance and activity of metabolic enzymes, which directly regulate sugar-acid metabolism.

In this study, seasonal variability was observed, location-specific soil properties changed throughout the study, and genotypic differences may influence crop response to nitrogen and phosphorus application. Consequently, different seasons and various location trials involving multiple cultivars are recommended to further validate and generalize the findings.

Pearson's Correlation Matrix

Annexure (B)

Pearson's correlation matrix exhibited prominent relationships among vegetative, reproductive, and quality attributes in pea. Plant height showed strong positive correlations with branches (r = 0.90), pods $plant^{-1}$ (r = 0.89), flowers $plant^{-1}$ (r = 0.87), total soluble solids (TSS; r = 0.91), and titratable acidity (r = 0.92), showing that taller plants produce more branches, flowers, and pods with maximum sugar and acidity content. Leaves showed strong positive correlations with pod length (r = 0.74) and seeds pod^{-1} (r = 0.69), and moderate correlations with pods $plant^{-1}$ (r = 0.57) and flowers $plant^{-1}$ (r = 0.55), indicating that enhanced leaf development supports the yield and quality of the pod. Branches were highly correlated with pods $plant^{-1}$ (r = 0.93), flowers $plant^{-1}$ (r = 0.89), TSS (r = 0.94), and titratable acidity (r = 0.91), pointing to the importance of vegetative development in observing yield and quality. Pods $plant^{-1}$ showed a relatively perfect correlation with flowers $plant^{-1}$ (r = 0.99), indicating that more flower numbers result in more pods. Seeds pod^{-1} were strongly linked with pod length (r = 0.92), exhibiting that longer pods results into more seeds, whereas correlations with other vegetative attributes were weaker. Quality traits such as TSS and titratable acidity were dominantly correlated with plant height, branches, and pods plant^{-1}, showing that pronounced growth and higher pod numbers increase sugar content and acidity. Contrastingly, pH showed negative correlations with the majority of growth and yield traits, including plant height (r = –0.69), leaves (r = –0.72), and pods plant^{-1} (r = –0.51), while positively correlating with floral initiation (days) (r = 0.86), indicating that plants with delayed flowering produced pods with higher pH.

Innovation Statement:

This research is innovative in that it thoroughly evaluates nitrogen–phosphorus (NP) integrative application under local soil and agro-climatic conditions, giving the location-oriented nutrient utilization for pea production. The present study simultaneously exhibits vegetative, reproductive, yield component, and pod quality attributes within a single experimental study. This integrative assessment allows examination of NP levels that hasten and increase productivity without compromising quality, thereby offering both physiological insight into nutrient response patterns and on-farm fertilizer recommendations structured for local farming systems.

Conclusion

The theoretical implications indicate that results showed balanced NP application enhances pea growth by increasing physiological processes such as photosynthesis, nutrient uptake, and efficient C: N metabolism, leading to better vegetative growth, yield formation, and pod quality. From a practical perspective, Level 4 (N 30 kg ha^{-1} and P 80 kg ha^{-1}) showed superior performance for most of the vegetative and reproductive parameters, followed by Level 3 (N 30 kg ha^{-1} and P 70 kg ha^{-1}) which showed better results for number of seeds pod^{-1} and pod length, in this treatment floral initiation (days) was quick as compared to the control and lower fertilizer doses.

Recommendation

The study recommends that nitrogen at 30 kg ha^{-1} combined with phosphorus at 80 kg ha^{-1} be applied for pea cultivation in nutrient-deficient soils to achieve optimum growth, yield, and pod quality. This fertilizer combination may contribute to sustainable pea production by ensuring efficient nutrient utilization. This integrative application of fertilizers is important for the commercial production of peas. Further studies are suggested to validate these results under different agro-climatic conditions and to assess the long-term effects of this nutrient management strategy on soil fertility, which is a major factor in the commercial cultivation of pea plants.

Ethical statement

This study followed institutional guidelines for agricultural research.

Authors' Contribution

AT: Experimental design, field management, data collection, and manuscript drafting, N-U-N M: Conceptualization and Supervision, NAW: Supervision and critical review of the manuscript, BB: Manuscript editing and data interpretation, MAW: Field management and experiment implementation, MFJ: Guidance, manuscript revision, and editing, ARJ: Field management and quality assessment, AAH: Field management, experiment implementation, data collection and interpretation.

Competing Interest:

The authors declare that they have no competing interests related to this study.

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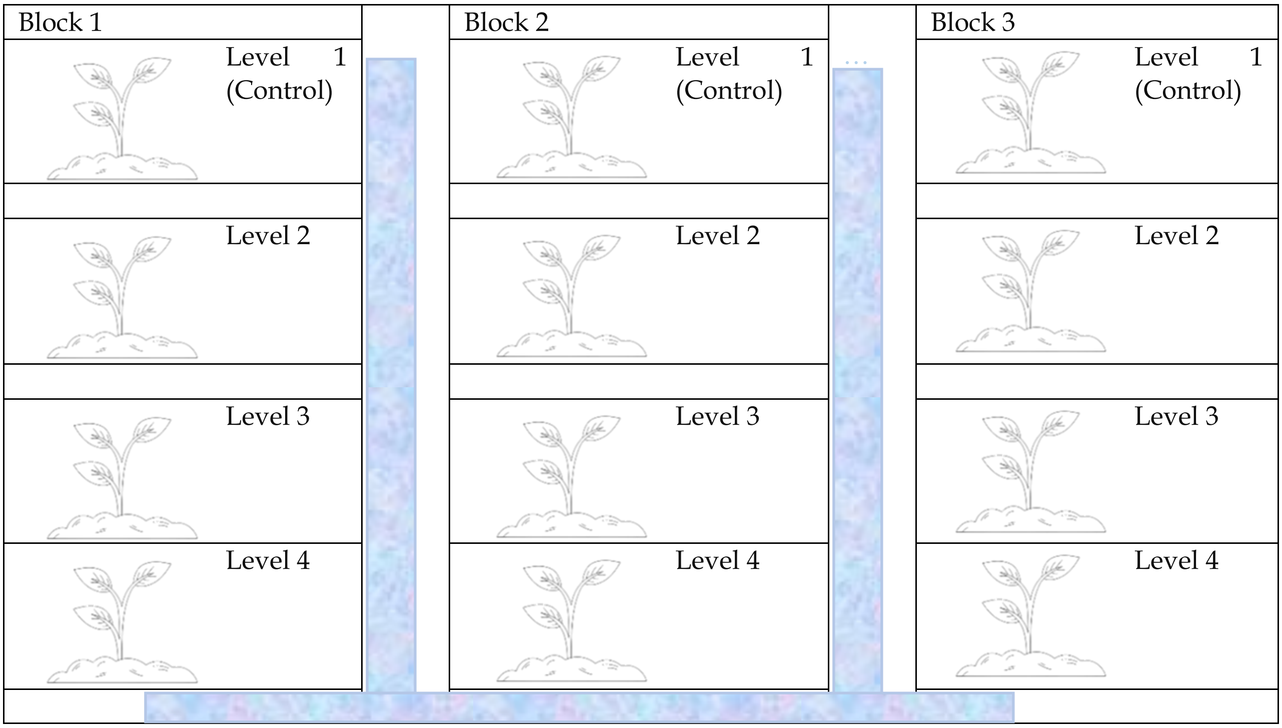
Annexure (A)

Area=423 square feet Irrigation channel



Annexure (B)

	Plant height	*Branches*	*Leaves*	*Pods/plant*	*Seeds/pod*	*Pod length*	*Days to flowering*	*Flowers/plant*	*pH*	*Titratable acidity*	*TSS*
Plant height	1										
Branches	0.90444176	1									
Leaves	0.59964031	0.372063	1								
Pods/plant	0.88915213	0.927876	0.570544	1							
Seeds/pod	0.13081109	0.084762	0.693454	0.27558044	1						
Pod length	0.22952278	0.142919	0.739469	0.27200009	0.920865122	1					
Days to flowering	-0.6483578	-0.41856	-0.79661	-0.51564768	-0.453488424	-0.60735227	1				
Flowers/plant	0.87062617	0.894744	0.54671	0.98537257	0.286975438	0.255535067	-0.457744606	1			
pH	-0.6932898	-0.3719	-0.72183	-0.50985335	-0.238254229	-0.35837017	0.855039036	-0.509239032	1		
Titratable acidity	0.91916784	0.911625	0.426684	0.85655098	0.091780748	0.133541354	-0.564728596	0.84455989	-0.55073	1	
TSS	0.90992925	0.942629	0.533542	0.92786285	0.132226375	0.186085295	-0.47258945	0.897465404	-0.4273	0.893545135	1