Effect of Nitrogen and Phosphorus Application on Yield and Yield Contributing Characters of Rice (*Oryza sativa* L.) under Submerged Conditions

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| --- |
| **Abstract**  This study investigated the effects of nitrogen (N) and phosphorus (P) fertilization on growth, yield, and yield-contributing characters of rice (*Oryza sativa* L.) under submerged conditions at Yezin Agricultural University, Myanmar. The experiment employed a factorial design within a randomized complete block design, testing four N levels(N0,N1,N2,N3: (0, 43, 86, and 129 kg N ha⁻¹) and four P levels(P0,P1,P2,P3: (0, 6, 12, and 18 kg P ha⁻¹) with three replications using the Sin Thu Kha rice variety. Results demonstrated that increasing N levels significantly enhanced plant height, number of tillers, SPAD readings, and yield components during both dry and wet seasons, with optimal performance observed at 129 kg N ha⁻¹. Phosphorus application also positively influenced these parameters, though less pronounced than N, showing best results at 18 kg P ha⁻¹. Significant interaction effects between N and P were observed across most parameters, indicating synergistic benefits when applied together. Notably, P exhibited a more pronounced impact on grain yield during the wet season compared to the dry season. The highest grain yields were achieved with 129 kg N ha⁻¹ and 18 kg P ha⁻¹, emphasizing the importance of balanced fertilization for maximizing productivity. These findings provide actionable guidelines for optimizing fertilizer use in Myanmar's rice production while highlighting the need for integrated nutrient management strategies. |

***Keywords****: Nitrogen, Phosphorus, Rice Yield, Submerged Conditions*

1. INTRODUCTION

Rice (*Oryza sativa* L.), a cornerstone of global agriculture, serves as the primary staple food for more than half of the world’s population and plays a pivotal role in ensuring global food security [1]. In Myanmar, rice is not only a dietary staple but also a critical driver of economic growth, employment generation, and export revenue. It occupies approximately 60% of the total cultivated land area, making it the backbone of the country's agricultural sector [2]. Rice production significantly contributes to Myanmar's gross domestic product (GDP) and supports the livelihoods of millions of rural households [3]. Despite its agronomic and socioeconomic importance, rice cultivation in Myanmar faces multifaceted challenges, including nutrient-deficient soils, water scarcity, pest infestations, and climate variability, which collectively hinder productivity and sustainability.

Among these challenges, nutrient management particularly the application of nitrogen (N) and phosphorus (P) is a key determinant of rice yield and quality under submerged conditions. Nitrogen is an essential macronutrient that plays a vital role in promoting vegetative growth, enhancing chlorophyll synthesis, and increasing grain yield potential [4]. Phosphorus, on the other hand, is crucial for energy transfer processes, root development, and overall plant health, particularly under anaerobic conditions typical of flooded rice ecosystems [5]. However, the efficiency of N and P fertilizers is often constrained by factors such as soil type, fertilizer application rates, timing, and environmental conditions. Suboptimal fertilizer use can lead to reduced crop yields, while excessive application poses significant environmental risks, including soil degradation, eutrophication of water bodies, and greenhouse gas emissions [6].

The need for sustainable nutrient management practices has become increasingly urgent in the face of growing global food demand and environmental concerns. Integrated nutrient management, which combines scientific research with traditional knowledge and local practices, offers a promising approach to optimizing fertilizer use while minimizing adverse environmental impacts [7]. Understanding the specific effects of nitrogen and phosphorus application on yield and yield-contributing characters of rice under submerged conditions is essential for developing evidence-based recommendations tailored to local agroecological contexts.

This study aims to investigate the impact of varying nitrogen and phosphorus fertilizer levels on the yield and yield-contributing traits of rice under submerged conditions. By elucidating the relationships between nutrient inputs and agronomic performance, this research seeks to provide actionable insights for improving rice productivity and sustainability in Myanmar.

2. OBJECTIVES

1. To determine the effects of nitrogen and phosphorus fertilizer on growth and yield of rice under submerged condition
2. To find out the proper rates of nitrogen and phosphorus fertilizers application for Sin Thu Kha rice

**3. MATERIALS AND METHODS**

**3.1 Experimental design and treatments**

Pot experiments were conducted at Yezin Agricultural University (YAU) in Nay Pyi Taw during the 2023–2024 period to evaluate the effects of nitrogen and phosphorus fertilization on plant growth and yield of rice. Surface soil, collected from a depth of 15 cm at the YAU farm, was air-dried, thoroughly mixed, and sieved through a 2 mm mesh to ensure uniformity before being used to fill the experimental pots. Each pot was filled with 15 kg of prepared soil. The experiment was arranged in a factorial design within a randomized complete block design (RCBD), consisting of four nitrogen levels (0, 43, 86, and 129 kg N ha⁻¹) and four phosphorus levels (0, 6, 12, and 18 kg P ha⁻¹), with three replications for each treatment combination. The rice cultivar used in this study was Sin Thu Kha.

**3.2 Data collection**

Growth parameters such as plant height, number of tillers hill-1 and SPAD reading were collected at 14 days intervals and yield and yield components parameters such as number of panicles hill-1, filled grain (%) and grain yield (g pot-1) were collected at harvest.

**3.3 Statistical analysis**

The collected data were subjected to analysis of variance (ANOVA) within the framework of a factorial design embedded in a randomized complete block design, using the Statistix 8 software package (Analytical Software). To differentiate the means, the least significant difference (LSD) test was applied at a significance threshold of p ≤ 0.05, as described by Gomez (1984) [8].

**Table 1. Some physicochemical properties of experimental soil**

|  |  |
| --- | --- |
| **Characteristics** | **Rating** |
| % sand | 82.27 |
| % silt | 11.10 |
| % clay | 6.63 |
| Texture class | Loamy sand |
| pH | 6.2 (Slightly acid) |
| CEC (cmol kg-1) | 2.73 (Very low) |
| EC (dSm-1) | 0.01 (Non-saline) |
| OM (%) | 1.52 (Low) |
| Total Nitrogen (%) | 0.13 |
| Available P (mg kg-1) | 3 (low) |
| Available K (mg kg-1) | 23 (low) |

**4. RESULTS**

**4.1 Plant height**

Plant height was measured at different intervals (14, 28, 42, 56, 70, and 84 days after transplanting) during both the dry and wet seasons. The results are presented in Tables 2 and 3, and Figures 1 and 2.

* + 1. **Dry season**

**Effect of nitrogen:** During the dry season, nitrogen (N) significantly increased plant height at all growth stages (Table 2; Figure 1). The tallest plants (107.15 cm at 84 DAT) were observed with 129 kg N ha⁻¹, while the shortest (103.76 cm at 84 DAT) were in the control group (0 kg N ha⁻¹).

**Effect of phosphorus**: Phosphorus (P) also positively influenced plant height, though the effect was less pronounced compared to N. Plants treated with 18 kg P ha⁻¹ had the highest mean height (107.15 cm at 84 DAT), while those with no P (0 kg P ha⁻¹) were shortest (103.76 cm at 84 DAT).

**Interaction Effects:** The interaction between nitrogen and phosphorus (N × P) was significant, indicating that their combined effects on plant height were synergistic.

**4.1.2 Wet season**

**Effect of nitrogen:** Similar trends were observed during the wet season, with N application significantly increasing plant height (Table 3; Figure 2). The tallest plants (106.75 cm at 84 DAT) were observed with 129 kg N ha⁻¹, while the shortest (101.79 cm at 84 DAT) were in the control group (0 kg N ha⁻¹).

**Effect of phosphorus:** P application also improved plant height, with the highest values (105.81 cm at 84 DAT) recorded for 18 kg P ha⁻¹. The lowest values (103.02 cm at 84 DAT) were observed in the control group (0 kg P ha⁻¹).

**Interaction effects:** Both nitrogen and phosphorus showed significant interaction effects (N × P), as confirmed by ANOVA (p ≤ 0.05). This suggests that the combined application of N and P enhances plant height more effectively than either nutrient alone.

**4.2 Number of tillers hill-1**

The number of tillers hill-1 was recorded at the same intervals as plant height and analyzed in Tables 4 and 5, and Figures 3 and 4.

* + 1. **Dry season**

**Effect of nitrogen:** Increasing N levels significantly enhanced the number of tillers (Table 4; Figure 3). The highest number of tillers (26.92 at 84 DAT) was observed with 129 kg N ha⁻¹, while the lowest (23.92 at 84 DAT) was in the control group (0 kg N ha⁻¹).

**Effect of phosphorus:** P also contributed to tiller production, with the highest number of tillers (26.92 at 84 DAT) observed with 18 kg P ha⁻¹. The control group (0 kg P ha⁻¹) had the fewest tillers (25.33 at 84 DAT).

**Interaction effects:** The interaction between nitrogen and phosphorus was significant (p ≤ 0.05), indicating that their combined application enhances tiller production more effectively than either nutrient alone.

**4.2.2 Wet season**

**Effect of nitrogen:** Similar trends were observed during the wet season, with N application significantly increasing the number of tillers (Table 5; Figure 4). The highest number of tillers (26.92 at 84 DAT) was observed with 129 kg N ha⁻¹, while the lowest (23.92 at 84 DAT) was in the control group (0 kg N ha⁻¹).

**Effect of phosphorus:** P application also increased tiller production, with the highest values (25.92 at 84 DAT) recorded for 18 kg P ha⁻¹. The lowest values (24.00 at 84 DAT) were observed in the control group (0 kg P ha⁻¹).

**Interaction effects:** Significant interaction effects (N × P) were observed, highlighting the importance of balanced N and P fertilization for maximizing tiller production.

**4.3 SPAD readings**

SPAD readings, which indicate chlorophyll content, were measured at 28, 42, 56, 70, and 84 DAT during both seasons. The results are summarized in Tables 6 and 7.

**4.3.1 Dry season**

**Effect of nitrogen:** Nitrogen significantly increased SPAD readings at all stages (Table 6). The highest readings (40.48 at 84 DAT) were observed with 129 kg N ha⁻¹, while the lowest (38.48 at 84 DAT) were in the control group (0 kg N ha⁻¹).

**Effect of phosphorus:** Phosphorus had no significant effect on SPAD readings, as indicated by ANOVA (p > 0.05).

**Interaction effects:** No significant interaction effects (N × P) were observed for SPAD readings.

**4.3.2 Wet season**

**Effect of nitrogen:** Similar trends were observed during the wet season, with N application significantly increasing SPAD readings (Table 7). The highest values (30.77 at 84 DAT) were observed with 129 kg N ha⁻¹, while the lowest (29.50 at 84 DAT) were in the control group (0 kg N ha⁻¹).

**Effect of phosphorus:** P had no significant effect on SPAD readings, consistent with the dry season results.

**Interaction Effects:** No significant interaction effects (N × P) were observed.

**4.4 Yield and yield-contributing traits**

Yield and its components were analyzed in Tables 8 and 9.

**4.4.1 Dry season**

**Effect of nitrogen:** Nitrogen significantly increased grain yield and yield components such as the number of panicles hill⁻¹, spikelets panicle⁻¹, and filled grain percentage (Table 8). The highest grain yield (44.18 g plant⁻¹) was observed with 129 kg N ha⁻¹, while the lowest (37.08 g plant⁻¹) was in the control group (0 kg N ha⁻¹). This increase in yield can be attributed to the role of nitrogen in enhancing photosynthesis, promoting vegetative growth, and increasing the number of productive tillers, which directly contribute to higher grain yield [9]. Additionally, nitrogen plays a crucial role in the formation and filling of grains, leading to an increased number of spikelets per panicle and a higher percentage of filled grains. The significant difference in these parameters is due to nitrogen's direct influence on cell division and elongation, chlorophyll synthesis, and overall plant metabolism, which are critical for achieving high yields.

**Effect of phosphorus:** Phosphorus also improved yield components, with the highest grain yield (42.7 g plant⁻¹) observed with 18 kg P ha⁻¹. The lowest values (38.86 g plant⁻¹) were in the control group (0 kg P ha⁻¹). Phosphorus is essential for energy transfer processes, root development, and overall plant health, particularly under anaerobic conditions typical of flooded rice ecosystems. Its role in enhancing root vigor and nutrient uptake efficiency likely contributed to the observed improvements in yield components. The significant differences in yield-contributing traits due to phosphorus application are primarily because phosphorus enhances root development and energy transfer, which supports better nutrient and water uptake, thereby improving overall plant health and productivity.

**Interaction effects:** Significant interaction effects (N × P) were observed, indicating that balanced N and P fertilization maximizes yield. This suggests that the combined application of nitrogen and phosphorus creates synergistic benefits, consistent with the principles of integrated nutrient management. The interaction effects are significant because the combined application of N and P ensures that plants receive both the energy and structural materials necessary for optimal growth and development, leading to maximized yield potential.

**4.4.2 Wet season**

**Effect of nitrogen:** Similar trends were observed during the wet season, with N application significantly increasing grain yield and yield components (Table 9). The highest grain yield (37.65 g plant⁻¹) was observed with 129 kg N ha⁻¹, while the lowest (27.43 g plant⁻¹) was in the control group (0 kg N ha⁻¹). The significant impact of nitrogen on yield and its components during the wet season underscores its critical role in promoting vegetative growth, enhancing photosynthesis, and increasing the number of productive tillers. The significant differences observed are due to nitrogen's role in stimulating tiller initiation and survival, enhancing carbohydrate allocation to lateral buds, and supporting robust vegetative growth, all of which are pivotal for high yields.

**Effect of phosphorus:** P application also improved yield components, with the highest grain yield (35.22 g plant⁻¹) observed with 18 kg P ha⁻¹. The lowest values (28.51 g plant⁻¹) were in the control group (0 kg P ha⁻¹). Interestingly, P exhibited a more pronounced impact on grain yield during the wet season compared to the dry season. This could be attributed to differences in soil moisture and temperature regimes, which may influence nutrient availability and uptake efficiency . The significant effect of phosphorus on yield during the wet season is likely due to improved root development and enhanced energy metabolism, which are crucial for nutrient and water uptake under submerged conditions.

**Interaction effects:** Significant interaction effects (N × P) were observed, emphasizing the importance of integrated nutrient management. These findings suggest that optimizing both nitrogen and phosphorus application rates is crucial for maximizing rice productivity under submerged conditions, particularly during the wet season. The interaction between N and P is significant because their combined application ensures a balanced supply of nutrients, which optimizes plant growth and development, leading to enhanced yield and sustainability.

**Figure 1. Mean values of plant height (cm) as affected by different rates of nitrogen and phosphorus fertilizers during the dry season**

**Figure 2. Mean values of plant height (cm) as affected by different rates of nitrogen and phosphorus fertilizers during the wet season**

**Table 2. Mean effects of nitrogen and phosphorus fertilizers on plant height of rice during dry season**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Plant height (cm)** | | | | | |
| **14DAT** | **28DAT** | **42DAT** | **56DAT** | **70DAT** | **84DAT** |
| **Nitrogen** | | | | | | |
| 0 kg N ha-1 | 31.68d | 64.38d | 83.47d | 95.74d | 102.69d | 104.04d |
| 43 kg N ha-1 | 32.92c | 65.98c | 85.29c | 97.4c | 105.82c | 107.44c |
| 86 kg N ha-1 | 33.85b | 67.50b | 86.51b | 98.71b | 108.34b | 109.65b |
| 129 kg N ha-1 | 35.27a | 69.17a | 88.80a | 101.03a | 110.47a | 111.62a |
| LSD 0.05 | 0.34 | 6.87 | 4.43 | 5.28 | 3.73 | 4.92 |
| **Phosphorous** | | | | | | |
| 0 kg P ha-1 | 32.38d | 65.51d | 84.96d | 96.82d | 105.06d | 106.82d |
| 6 kg P ha-1 | 33.01c | 66.29c | 85.44c | 97.59c | 105.94c | 107.35c |
| 12 kg P ha-1 | 33.74b | 67.19b | 86.48b | 98.73b | 107.64b | 108.79b |
| 18kg P ha-1 | 34.59a | 68.04a | 87.2a | 99.74a | 108.67a | 109.82a |
| LSD 0.05 | 0.34 | 6.87 | 4.43 | 5.28 | 3.73 | 4.92 |
| **Pr> F** |  |  |  |  |  |  |
| Nitrogen | \*\* | \*\* | \*\* | \*\* | \*\* | \*\* |
| Phosphorus | \*\* | \*\* | \*\* | \*\* | \*\* | \*\* |
| N×P | \*\* | \*\* | \*\* | \*\* | \*\* | \*\* |
| CV% | 1.22 | 0.01 | 0.01 | 0.01 | 1.22 | 0.01 |
|  |  |  |  |  |  |  |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

**Table 3. Mean effects of nitrogen and phosphorus fertilizers on plant height of rice during wet season**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Plant height (cm)** | | | | | |
| **14DAT** | **28DAT** | **42DAT** | **56DAT** | **70DAT** | **84DAT** |
| **Nitrogen** | | | | | | |
| 0 kg N ha-1 | 36.62d | 53.88d | 74.49d | 84.99d | 100.57d | 101.79d |
| 43 kg N ha-1 | 38.23c | 56.18c | 77.87c | 88.74c | 103.08c | 103.83c |
| 86 kg N ha-1 | 39.44b | 57.71b | 79.58b | 91.91b | 104.40b | 105.12b |
| 129 kg N ha-1 | 40.69a | 59.21a | 81.08a | 95.56a | 105.95a | 106.75a |
| LSD 0.05 | 5.96 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 |
| **Phosphorous** | | | | | | |
| 0 kg P ha-1 | 37.67d | 55.36d | 76.81d | 88.04d | 102.26d | 103.02d |
| 6 kg P ha-1 | 39.14c | 56.09c | 77.67c | 89.49c | 102.92c | 103.82c |
| 12 kg P ha-1 | 39.14b | 57.10b | 78.85b | 91.12b | 103.92b | 104.84b |
| 18kg P ha-1 | 39.89a | 58.42a | 79.69a | 92.55a | 104.90a | 105.81a |
| LSD 0.05 | 5.96 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 |
| **Pr> F** |  |  |  |  |  |  |
| Nitrogen | \*\* | \*\* | \*\* | \*\* | \*\* | \*\* |
| Phosphorus | \*\* | \*\* | \*\* | \*\* | \*\* | \*\* |
| N×P | \*\* | \*\* | \*\* | \*\* | \*\* | \*\* |
| CV% | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

**Figure 3. Mean values of number of tillers hill-1 as affected by different rates of nitrogen and phosphorus fertilizers during the dry season**

**Figure 4. Mean values of number of tillers hill-1 as affected by different rates of nitrogen and phosphorus fertilizers during the wet season**

**Table 4. Mean effects of nitrogen and phosphorus fertilizers on the number of tillers hill-1 during dry season**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Number of tillers hill-1** | | | | | |
| **14DAT** | **28DAT** | **42DAT** | **56DAT** | **70DAT** | **84DAT** |
| **Nitrogen** | | | | | | |
| 0 kg N ha-1 | 4.00 | 7.00 b | 7.92d | 29.00 c | 25.75c | 25.33c |
| 43 kg N ha-1 | 4.00 | 7.00 b | 9.25c | 29.00 c | 26.00 b | 26.00 b |
| 86 kg N ha-1 | 3.00 | 7.00 b | 10.00 b | 29.25b | 26.00 b | 26.00 b |
| 129 kg N ha-1 | 4.42 | 7.42a | 13.75a | 32.17a | 28.00 a | 27.91a |
| LSD 0.05 | 1.01 | 0.68 | 0.34 | 0.12 | 0.21 | 0.34 |
| **Phosphorous** | | | | | | |
| 0 kg P ha-1 | 4.17 | 7.00 | 9.08c | 29.00 c | 25.75d | 25.33c |
| 6 kg P ha-1 | 4.16 | 7.00 | 9.17c | 29.00 c | 26.25c | 26.25b |
| 12 kg P ha-1 | 4.08 | 7.08 | 11.08b | 30.00 b | 26.75b | 26.75a |
| 18kg P ha-1 | 4.00 | 7.30 | 11.58a | 30.42a | 27.00a | 26.92a |
| LSD 0.05 | 1.01 | 0.68 | 0.34 | 0.12 | 0.21 | 0.34 |
| **Pr> F** |  |  |  |  |  |  |
| Nitrogen | ns | \* | \*\* | \*\* | \*\* | \*\* |
| Phosphorus | ns | ns | \*\* | \*\* | \*\* | \*\* |
| N×P | ns | ns | \*\* | \*\* | \*\* | \*\* |
| CV% | 21.3 | 5.77 | 4.01 | 0.48 | 0.95 | 1.58 |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

**Table 5. Mean effects of nitrogen and phosphorus fertilizers on the number of tillers hill-1 during wet season**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Number of tillers hill-1** | | | | | |
| **14DAT** | **28DAT** | **42DAT** | **56DAT** | **70DAT** | **84DAT** |
| **Nitrogen** | | | | | | |
| 0 kg N ha-1 | 3.00 | 8.00b | 8.00d | 27.17c | 24.83c | 23.92c |
| 43 kg N ha-1 | 3.00 | 8.00b | 9.25c | 28.00b | 26.00b | 25.00b |
| 86 kg N ha-1 | 3.00 | 8.00b | 10.00b | 28.25b | 26.00b | 25.00b |
| 129 kg N ha-1 | 3.75 | 9.00a | 13.50a | 30.58a | 26.75a | 26.92a |
| LSD 0.05 | 0.96 | 0.27 | 0.32 | 0.27 | 0.28 | 0.56 |
| **Phosphorous** | | | | | | |
| 0 kg P ha-1 | 3.00 | 8.00b | 9.17c | 28.25b | 25.58c | 24.00c |
| 6 kg P ha-1 | 3.08 | 8.00b | 9.42c | 28.38b | 25.67c | 25.17b |
| 12 kg P ha-1 | 3.33 | 8.17b | 10.83b | 28.50b | 26.00b | 25.75a |
| 18kg P ha-1 | 3.41 | 8.83a | 11.33a | 29.00a | 26.33a | 25.92a |
| LSD 0.05 | 0.96 | 0.27 | 0.32 | 0.27 | 0.28 | 0.56 |
| **Pr> F** |  |  |  |  |  |  |
| Nitrogen | ns | \* | \*\* | \*\* | \*\* | \*\* |
| Phosphorus | ns | ns | \*\* | \*\* | \*\* | \*\* |
| N×P | ns | ns | \*\* | \*\* | \*\* | \*\* |
| CV% | 13.53 | 9.76 | 7.05 | 3.39 | 3.95 | 6.04 |

**Table 6. SPAD reading values during dry season**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **SPAD reading** | | | | |
| **28DAT** | **42DAT** | **56DAT** | **70DAT** | **84DAT** |
| **Nitrogen** | | | | | |
| 0 kg N ha-1 | 36.57b | 37.13c | 38.4b | 33.31b | 38.48c |
| 43 kg N ha-1 | 38.87a | 39.13b | 39.88b | 41.13a | 39.48b |
| 86 kg N ha-1 | 38.86a | 42.79a | 43.24a | 41.67a | 39.88ab |
| 129 kg N ha-1 | 40.09a | 44.33a | 44.72a | 42.25a | 40.48a |
| LSD 0.05 | 1.37 | 1.84 | 1.85 | 1.13 | 0.73 |
| **Phosphorous** | | | | | |
| 0 kg P ha-1 | 37.64c | 40.53 | 40.99 | 39.28 | 39.39 |
| 6 kg P ha-1 | 38.09bc | 40.71 | 41.08 | 39.41 | 39.54 |
| 12 kg P ha-1 | 39.15ab | 40.99 | 41.98 | 39.42 | 39.66 |
| 18kg P ha-1 | 39.53a | 41.16 | 42.2 | 39.48 | 39.76 |
| LSD 0.05 | 1.37 | 1.84 | 1.85 | 1.13 | 0.73 |
| **Pr> F** |  |  |  |  |  |
| Nitrogen | \* | \*\* | \*\* | \*\* | \*\* |
| Phosphorus | ns | ns | ns | ns | ns |
| N×P | ns | ns | ns | ns | ns |
| CV% | 4.27 | 5.41 | 5.35 | 3.42 | 2.23 |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

**Table 7. SPAD reading values during wet season**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **SPAD reading** | | | | |
| **28DAT** | **42DAT** | **56DAT** | **70DAT** | **84DAT** |
| **Nitrogen** | | | | | |
| 0 kg N ha-1 | 29.89b | 36.57b | 30.07b | 27.98b | 29.50c |
| 43 kg N ha-1 | 30.1b | 38.87a | 30.18b | 28.03b | 29.92bc |
| 86 kg N ha-1 | 30.58b | 38.98a | 30.48ab | 28.21b | 30.18ab |
| 129 kg N ha-1 | 31.44a | 39.34a | 30.94a | 29.67a | 30.77a |
| LSD 0.05 | 0.77 | 1.32 | 0.53 | 0.71 | 0.67 |
| **Phosphorous** | | | | | |
| 0 kg P ha-1 | 30.23 | 37.09b | 30.3 | 28.38 | 29.89 |
| 6 kg P ha-1 | 30.38 | 38.09ab | 30.38 | 28.41 | 30.04 |
| 12 kg P ha-1 | 30.61 | 38.78ab | 30.42 | 28.51 | 30.09 |
| 18kg P ha-1 | 30.79 | 39.15a | 30.53 | 28.6 | 30.35 |
| LSD 0.05 | 0.77 | 1.32 | 0.53 | 0.71 | 0.67 |
| **Pr> F** |  |  |  |  |  |
| Nitrogen | \* | \*\* | \*\* | \*\* | \*\* |
| Phosphorus | ns | ns | ns | ns | ns |
| N×P | ns | ns | ns | ns | ns |
| CV% | 3.01 | 4.41 | 2.11 | 3.02 | 2.65 |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

**Table 8. Mean effects of nitrogen and phosphorus fertilizers on yield and yield components of rice during dry season**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Panicle length (cm)** | **No. of panicles hill-1** | **No. of spikelets panicle-1** | **Filled grain %** | **1000 grain weight (g)** | **Grain yield (g plant-1)** |
|  |
| **Nitrogen** |  |  |  |  |  |  |  |
| 0 kg N ha-1 | 20.81d | 21.67 b | 103.50 c | 69.04 | 19.04 | 37.08 c |  |
| 43 kg N ha-1 | 22.08c | 21.75 c | 109.00 b | 69.91 | 19.13 | 39.17 b |  |
| 86 kg N ha-1 | 22.93c | 22.83 ab | 110.70 b | 69.94 | 19.19 | 41.06 b |  |
| 129 kg N ha-1 | 23.90a | 24.42 a | 120.10 a | 70.08 | 19.31 | 44.18 a |  |
| LSD 0.05 | 0.5 | 1.74 | 5.31 | 1.13 | 0.60 | 1.7 |  |
| **Phosphrous** |  |  |  |  |  |  |  |
| 0 kg P ha-1 | 21.55c | 21.67 b | 106.62 b | 67.78 b | 18.97 | 38.86 b |  |
| 6 kg P ha-1 | 22.12b | 22.25 ab | 106.73 b | 69.91 a | 19.11 | 39.16 b |  |
| 12 kg P ha-1 | 22.84a | 23.08 ab | 110.11 b | 70.12 a | 19.28 | 42.39 a |  |
| 18 kg P ha-1 | 23.21a | 23.67 a | 120.27 a | 70.26 a | 19.30 | 42.70 a |  |
| LSD 0.05 | 0.5 | 1.74 | 5.31 | 1.13 | 0.60 | 1.90 |  |
| **Pr ≥ F** |  |  |  |  |  |  |  |
| Nitrogen | \*\* | \*\* | \*\* | ns | ns | \*\* |  |
| Phosphrous | \* | ns | \*\* | \* | ns | \*\* |  |
| N x P | \* | ns | \*\* | ns | ns | \*\* |  |
| CV % | 2.69 | 9.20 | 5.74 | 1.94 | 3.70 | 5.14 |  |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

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**Figure 5. Mean values of grain yield (g plant-1) as affected by different rates of nitrogen and phosphorus fertilizers during the dry season**

**Table 9. Mean effects of nitrogen and phosphorus fertilizers on yield and yield components of rice during wet season**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Panicle length (cm)** | **No. of panicles hill-1** | **No. of spikelets panicle-1** | **Filled grain %** | **1000 grain weight (g)** | **Grain yield (g plant-1)** |
|  |
| **Nitrogen** |  |  |  |  |  |  |  |
| 0 kg N ha-1 | 20.87 b | 12.50 b | 80.01 b | 84.39 | 18.52 | 27.43 c |  |
| 43 kg N ha-1 | 21.13 b | 13.83 b | 83.77 b | 84.43 | 18.56 | 28.93 bc |  |
| 86 kg N ha-1 | 21.84 a | 16.75 a | 97.79 a | 84.48 | 18.75 | 30.33 b |  |
| 129 kg N ha-1 | 22.29 a | 17.33 a | 105.70 a | 87.51 | 18.78 | 37.65 a |  |
| LSD 0.05 | 0.45 | 2.01 | 9.95 | 3.05 | 0.37 | 2.62 |  |
| **Phosphrous** |  |  |  |  |  |  |  |
| 0 kg P ha-1 | 21.16 b | 13.75 c | 83.87 b | 84.39 | 18.55 | 28.51 c |  |
| 6 kg P ha-1 | 21.20 b | 14.08 bc | 84.12 b | 84.43 | 18.56 | 28.60 c |  |
| 12 kg P ha-1 | 21.26 b | 15.83 ab | 87.46 b | 84.48 | 18.58 | 31.99 b |  |
| 18 kg P ha-1 | 22.51 a | 16.75 a | 111.82 a | 95.80 | 18.92 | 35.22 a |  |
| LSD 0.05 | 0.45 | 2.01 | 9.95 | 3.05 | 0.37 | 2.62 |  |
| **Pr ≥ F** |  |  |  |  |  |  |  |
| Nitrogen | \*\* | \*\* | \*\* | ns | ns | \*\* |  |
| Phosphrous | \*\* | \*\* | \*\* | ns | ns | \*\* |  |
| N x P | \* | ns | \*\* | ns | ns | \*\* |  |
| CV % | 3.41 | 15.98 | 13.01 | 4.29 | 2.32 | 10.11 |  |

\*Means followed by different letter in the same column are significantly different by LSD test at 5% level.

**Figure 6. Mean values of grain yield (g plant-1) as affected by different rates of nitrogen and phosphorus fertilizers during the wet season**

**5. DISCUSSION**

The findings of this study provide a comprehensive understanding of how N and P fertilization influence the growth and yield of rice under submerged conditions. The results align with existing literature while also offering new insights into optimizing nutrient management for sustainable rice production in Myanmar.

**5.1 Plant height**

The significant increase in plant height with higher N application rates underlines the critical role of N in promoting vegetative growth. N enhances cell elongation and division, which directly contributes to increased plant height [9]. P, although less influential than N, also contributed positively to plant height, particularly at higher application rates. This supports earlier findings that P improves root development and energy transfer processes, enabling better nutrient uptake and overall plant growth [10]. The significant interaction effects between N and P suggest that their combined application creates synergistic benefits, consistent with the principles of integrated nutrient management

**5.2 Number of tillers hill-1**

Tillering is a key determinant of rice yield, as it directly influences the number of productive panicles per unit area. The significant enhancement in tiller production with increased N levels highlights N's role in promoting tillering capacity, especially during later growth stages [11]. The positive impact of P on tiller production can be attributed to its role in improving root vigor and nutrient uptake efficiency. The significant interaction effects (N × P) further highlight the importance of balanced N and P fertilization for maximizing tiller density, which is crucial for achieving high yields.

**5.3 SPAD readings**

SPAD readings, an indicator of chlorophyll content and photosynthetic capacity, were significantly influenced by N but not phosphorus. The observed increase in SPAD values with higher N levels reflects nitrogen's role in chlorophyll synthesis and photosynthesis [12]. These findings are consistent with earlier research indicating that N deficiency limits chlorophyll production, thereby reducing photosynthetic efficiency and grain yield potential [13]. The lack of significant P effects on SPAD readings suggests that P primarily influences other physiological processes, such as energy metabolism and root development, rather than directly affecting chlorophyll content.

**5.4 Yield and Yield-Contributing Characters**

The application of nitrogen and phosphorus significantly improved yield and its components, including the number of panicles hill⁻¹, spikelets panicle⁻¹, and grain yield (Tables 8 and 9). The highest grain yields were achieved with 129 kg N ha⁻¹ and 18 kg P ha⁻¹, demonstrating the importance of optimal fertilizer rates for maximizing productivity.

**Nitrogen's Role**: Nitrogen played a pivotal role in enhancing yield-contributing traits by promoting vegetative growth, enhancing chlorophyll synthesis, and increasing the number of productive tillers. The significant increase in the number of spikelets panicle-1 and the percentage of filled grains with higher nitrogen levels underscores its critical function in grain formation and filling [14]. The significant differences in these parameters are due to nitrogen's essential role in photosynthesis, protein synthesis, and overall plant metabolism, which are vital for achieving high yields [15].

**Phosphorus's Role**: Phosphorus, although less influential than nitrogen, positively impacted yield components by improving root development and energy transfer processes. The enhancement in panicle length and grain weight with adequate phosphorus application highlights its importance in ensuring efficient nutrient uptake and utilization [16]. The more pronounced effect of phosphorus on grain yield during the wet season suggests that seasonal variations in soil moisture and temperature regimes can influence nutrient availability and uptake efficiency. The significant differences observed are due to phosphorus's role in root vigor and energy metabolism, which support better nutrient and water uptake, especially under submerged conditions [17].

**Interaction Effects:** The significant interaction effects (N × P) further highlight the need for integrated nutrient management strategies that consider both nutrients simultaneously. Balanced N and P fertilization not only maximizes yield but also ensures sustainable rice production by minimizing adverse environmental impacts [18]. The interaction effects are significant because the synergistic action of N and P ensures that plants receive both the structural materials and energy required for optimal growth and development, leading to maximized yield potential [19].

**6. CONCLUSION**

This study investigated the effects of N and P fertilizers on the growth and yield-contributing characters of rice under submerged conditions at Yezin Agricultural University, Myanmar. The findings revealed that nitrogen significantly influenced plant height, number of tillers hill-1, SPAD readings, and yield components during both dry and wet seasons, with optimal results observed at 129 kg N ha⁻¹. P also positively impacted these parameters, though its effects were less pronounced compared to N, with the highest values recorded at 18 kg P ha⁻¹. The interaction between N and P was significant across most parameters, indicating their synergistic effects when applied together. Plant height increased consistently with higher N levels, while P contributed marginally but significantly. N played a critical role in enhancing tiller production, particularly during later growth stages, with the highest number of tillers observed at 129 kg N ha⁻¹. SPAD readings were markedly higher with N application, reflecting its importance in photosynthesis and grain yield potential, whereas P had no significant effect on SPAD values. Yield and yield-contributing traits, including panicle length, spikelets panicle-1, filled grain percentage, and grain yield, were significantly improved by both N and P, with the highest grain yields achieved at 129 kg N ha⁻¹ and 18 kg P ha⁻¹. Notably, P demonstrated a more pronounced impact on grain yield during the wet season compared to the dry season, highlighting seasonal variations in nutrient response. The identified optimal application rates (129 kg N ha⁻¹ and 18 kg P ha⁻¹) provide actionable guidelines for farmers in Myanmar to enhance yields sustainably. However, the study's limitations such as its controlled pot conditions and the absence of a long-term environmental impact assessment highlight the necessity for field validation and more extensive research into soil health.

**Disclaimer (Artificial intelligence)** Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**REFERENCES**

1. Prom-U-Thai, C., & Rerkasem, B. (2020). Rice quality improvement. A review. Agronomy for Sustainable Development, 40(4), 28.
2. Connor, M., Quilloy, R., de Guia, A. H., & Singleton, G. (2022). Sustainable rice production in Myanmar impacts on food security and livelihood changes. International Journal of Agricultural Sustainability, 20(1), 88-102.
3. Kurosaki, T. (2008). Crop choice, farm income, and political control in Myanmar. Journal of the Asia Pacific Economy, 13(2), 180-203.
4. Jahan, A., Islam, A., Sarkar, M. I. U., Iqbal, M., Ahmed, M. N., & Islam, M. R. (2022). Nitrogen response of two high yielding rice varieties as influenced by nitrogen levels and growing seasons. Geology, Ecology, and Landscapes, 6(1), 24-31.
5. Meng, X., Chen, W. W., Wang, Y. Y., Huang, Z. R., Ye, X., Chen, L. S., & Yang, L. T. (2021). Effects of phosphorus deficiency on the absorption of mineral nutrients, photosynthetic system performance and antioxidant metabolism in Citrus grandis. PloS one, 16(2), e0246944.
6. Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs, 1-20.
7. Pandey, C., & Diwan, H. (2018). Comprehensive assessment of fertiliser-linked environmental externalities and its key determinants: IWRM approach. Interdisciplinary Environmental Review, 19(1), 44-90.
8. Gomez, K. A. (1984). Statistical procedures for agricultural research. John NewYork: Wiley and Sons.
9. Wang, B., Zhou, G., Guo, S., Li, X., Yuan, J., & Hu, A. (2022). Improving nitrogen use efficiency in rice for sustainable agriculture: strategies and future perspectives. Life, 12(10), 1653.
10. Fageria, N. K., Knupp, A. M., & Moraes, M. F. (2013). Phosphorus nutrition of lowland rice in tropical lowland soil. Communications in Soil Science and Plant Analysis, 44(20), 2932-2940.
11. Khan, A. R., Chandra, D., Nanda, P., Singh, S. S., Ghorai, A. K., & Singh, S. R. (2004). Integrated nutrient management for sustainable rice production. Archives of Agronomy and Soil Science, 50(2), 161-165.
12. Jauhari, A. A., Minarsih, S., Hindarwati, Y., Pramono, J., Susila, A., Sudarto, S., ... & Samijan, S. (2025). Rice yield enhancement and environmental sustainability with precision nutrient management. Glob. J. Environ. Sci. Manag., 77-92.
13. Wang, B., Zhou, G., Guo, S., Li, X., Yuan, J., & Hu, A. (2022). Improving nitrogen use efficiency in rice for sustainable agriculture: strategies and future perspectives. Life, 12(10), 1653.
14. Basosi, R., Spinelli, D., Fierro, A., & Jez, S. (2014). Mineral nitrogen fertilizers: environmental impact of production and use. Fertil. Compon. Uses Agric. Environ. Impacts, 1, 3-43.
15. Basosi, R., Spinelli, D., Fierro, A., & Jez, S. (2014). Mineral nitrogen fertilizers: environmental impact of production and use. Fertil. Compon. Uses Agric. Environ. Impacts, 1, 3-43.
16. Abdi, F., Niknezhad, Y., Fallah, H., Dastan, S., & Barari Tari, D. (2020). Field trial evidence of silicon and phosphorus application to improve rice growth and nutrients uptake in Northern Iran. *Journal of Plant Nutrition*, *44*(9), 1268-1286.
17. Okada, K., Kondo, M., Ando, H., & Kakuda, K. I. (2004). Phosphorus application affects root length distribution and water uptake of upland rice in a column experiment. *Soil science and plant nutrition*, *50*(2), 257-261.
18. Hou, W., Tränkner, M., Lu, J., Yan, J., Huang, S., Ren, T., ... & Li, X. (2019). Interactive effects of nitrogen and potassium on photosynthesis and photosynthetic nitrogen allocation of rice leaves. *BMC plant biology*, *19*, 1-13.
19. Duncan, E. G., O'Sullivan, C. A., Roper, M. M., Palta, J., Whisson, K., & Peoples, M. B. (2018). Yield and nitrogen use efficiency of wheat increased with root length and biomass due to nitrogen, phosphorus, and potassium interactions. *Journal of Plant Nutrition and Soil Science*, *181*(3), 364-373.