**Original Research Article**

**Influence of Nano DAP-based Phosphorus application through Seedling Dipping and Foliar Spray on growth, yield attributes and yield of transplanted Rice (*Oryza sativa* L.)**

**Abstract**

A field experiment was conducted at Agriculture Research Farm of Rama University, Mandhana, Kanpur, Uttar Pradesh, during the *kharif* season of 2024 to evaluate the influence of Nano DAP-Based Phosphorus application through seedling dipping and foliar spray on growth, yield attributes and yield of transplanted rice. The experiment consisted of ten treatment combinations, conducted in Randomized Complete Block Design (RCBD). All the recommended agronomic practices were adopted to raise the crop, while the fertilizer application was done as per the treatments. The results revealed that application of 75% recommended P + 100% recommended N and K+ seedling dipping with nano DAP @ 5 ml litre-1 + Foliar spray with nano DAP @ 4 ml litre-1 of water at 30 DAT proved most effective in enhancing growth parameters i.e., plant height, number of tillers m-2, leaf area index, and dry matter accumulation at all crop growth stages, yield attributes viz., number of effective tillers (424.15 m-2), grains penicle-1 (104.49), and panicle length (25.76 cm), grain yield (4.22 t ha-1), straw yield (6.08 t ha-1), biological yield (10.30 t ha-1) and harvest index (40.98%), which was statistically similar with the treatment where 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5 ml litre-1 + Foliar spray with nano DAP @ 4 ml litre-1 of water at 30 DAT, 50% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 5 ml litre-1 + 2 Foliar spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT, 50% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5 ml litre-1 + 2 Foliar spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT and 100% recommended N: P: K were applied, while significantly superior over rest of the treatments. Thus, it may be concluded that 25% substitution of DAP with seedling dipping with nano DAP @ 5 ml litre-1 and foliar spray of nano DAP @ 4 ml litre-1 at 30 DAT was found to be the most effective option for achieving higher growth and yield attributes performance, which ultimately produce more yield of transplanted rices.

**Keywords:** Nano DAP, transplanted rice**,** seedling dipping**,** foliar spray

1. **INTRODUCTION**

For about half of the world's population, rice (*Oryza sativa* L.) is a staple meal. About 35 to 40 percent of agricultural output in India comes from rice, which is mostly dependent on the prudent use of fertilizers. Unbalanced and careless use of inorganic fertilizers degrades soil health and thus lowers soil production. It has been discovered that the usage of inorganic fertilizers, such as urea, DAP, and MOP, has a reduced fertilizer use efficiency in rice crops. The ranges for nitrogen, phosphorus, and potassium are 20 to 50%, 10% to 25%, and 70% to 80%, respectively (Chinnamuthu & Boopathi, 2009). Leaching, losses from volatilization and denitrification, greenhouse gas emissions, and the build-up of heavy metals in soil and plant systems are only a few of the severe environmental issues brought on by the usage of chemical fertilizers. Chemical fertilizer is being overdosed due to conventional application methods. Nanotechnology has the potential to address these issues, and nano fertilizers offer a means of guaranteeing long-term soil health and increased agricultural yields.

Nanotechnology is a promising field of research which utilizes nano materials of less than 100 nm size, may offer an unprecedented opportunity to develop concentrated sources of plant nutrients having higher-absorption rate, utilization efficacy and minimum losses. One of the most important uses of nano technology is nano fertilizer, which improves the ability of the plants to absorb nutrients (Ditta, 2012). Nano fertilizers are being prepared by encapsulating plant nutrients into nano materials, employing thin coating of nano materials on plant nutrients and delivering in the form of nano sized emulsions. Nano pores and stomatal openings in plant leaves facilitate nano material uptake and their penetration deep inside leaves leading to higher nutrient use efficiency (NUE). Nano fertilizers have higher transport and delivery of nutrients through plasmodesmata, which are nano sized (50–60 nm) channels between cells. The higher NUE and significantly lesser nutrient losses of nano fertilizers lead to higher productivity (6–17%) and nutritional quality of field crops (Adhikari & Ramana, 2019). Nano-fertilizers provides nutrients in a slow and steady way to the crop as per the requirement in order to increase crop yield, improve quality and to improve the overall sustainability of agricultural systems (Tarafdar *et al.*, 2014).

The eco-friendly fertilizer Nano Di-ammonium phosphate in liquid formulations are manufactured by Nano Biotechnology Research Centre in association with Indian Farmers Fertilizers Cooperative Limited to avoid the imbalanced and excessive use of Di-ammonium phosphate. Nano Di-ammonium phosphate contains 8 per cent nitrogen and 16 per cent phosphorus by weight in its nano form. Seedling treatment and foliar application with Nano Di-ammonium phosphate effectively fulfils crop nitrogen and phosphorus requirement (Al-Khuzai & Al-Juthery, 2020). Seedling dipping with nano Di-ammonium phosphate enhances seedling vigor, promotes root growth which leads to higher biomass production (Attri *et al.,* 2023). Seedling dipping with nano Di-ammonium phosphate also results in 10 to 50% higher grain yield of rice with 40 to 60% reduction in applied phosphorus through Di-ammonium phosphate (Kumari *et al.,* 2017). However, foliar application of nano Diammonium phosphate enters the leaf through stomatal and cuticular pores which increase in phosphorus concentration not only in shoots but also in roots, which ultimately increases the rapid uptake of phosphorus by rice crop (Talboys *et al.,* 2020). With this perspective, the present investigation was carried out to evaluate the influence of Nano DAP-Based Phosphorus application through seedling dipping and foliar spray on growth, yield attributes and yield of transplanted rice (*Oryza sativa* L.).

1. **METHODS AND MATERIALS**

The field experiment took place at Rama University's Agriculture Research Farm in Mandhana, Kanpur, Uttar Pradesh, during the *kharif* season (June to November, 2024). The experimental site is located between 26° 34' to 26° 56' North latitude and 80° 13' to 80° 21' East longitude, at an elevation of 125.9 meters above sea level, and has a semi-arid climate with an average annual rainfall of about 890 mm, with 90% of that falling between mid-June and the end of September. The soil in the experimental field was sandy loam in texture, somewhat alkaline in nature, with an initial soil pH of 7.24, EC of 0.21 dS m-1, a medium organic carbon content of 0.40%, low available nitrogen (185.77 kg ha-1), low phosphorus (14.58 kg ha-1), and medium potassium (244.48 kg ha-1). Ten treatments comprising of T1: Control (0% P + 100% N and K), T2: 100% recommended N: P: K, T3: 75% recommended P + 100% Recommended N and K, T4: 50% recommended P + 100% Recommended N and K, T5: T3 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT, T6: T3 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT, T7: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT, T8: T4 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT, T9: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT, T10: T4 + seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT were assigned in a Randomized Compete Block Design replicated thrice. Rice variety sarju 52 was grown with the recommended agronomic practices during the years. The recommended dose of fertilizers 120 kg N, 60 kg P**2**O**5** and 60 kg K**2**O ha**-1** was applied through Urea, DAP and MOP as per the treatments. Rice seedling were dipped in nano DAP solution @ 2.5 ml litre-1 of water and 4 ml liter-1 of water for 15 minutes and then the crop was transplanted as per treatments. First foliar spray of nano DAP was done at 30 DAT and second spray of nano DAP was done at 75 DAT (one week before flowering) in case of two foliar sprays whereas single foliar spray was applied at 30 DAT only. The initial number of hills m-2 was recorded at 15 DAT, plant height, number of tillers m-2, dry matter accumulation, at different growth stages of rice crop. Leaf area index was computed by using the formula as given by yosihida *et al.* (1972).

Where, LAI: leaf area index.

Yield contributing characters like productive tillers, panicle length, number of grains panicle-1, test weight,biological yield, straw yield as well as grain yield were recorded at harvest. Harvest index was calculated by using the following formula:

Harvest index =

Where, biological yield= grain yield + straw yield.

The one season data was statistically analyzed as suggested by Gomez and Gomez (1984). Statistical significance was tested by F test at a critical difference (CD) of 0.05 level of probability.

1. **RESULT AND DISCUSSION**

3.1 *Effect on growth*

Growth characteristics such as plant height, number of tillers m-2, leaf area index, and dry matter accumulation represent the process of effective resource use in a more productive agricultural situation. Dramatic variation in growth parameters of rice was noticed due to different application of seedling dipping and foliar application of nano-DAP (Table 1). The maximum growth attributes viz; plant height (121.18 cm), number of tillers (442.53 m-2), leaf area index (4.54), and dry matter accumulation (1170.14 g m-2), were noticed with the application where 75% recommended P + 100% Recommended N and K + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T6) applied, which was significantly superior over rest of the treatments but was statistically similar with the application of 75% recommended P + 100% Recommended N and K + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T5), 50% recommended P + 100% Recommended N and K + seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT (T10), 50% recommended P + 100% Recommended N and K + seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT (T9) and 100% recommended N: P: K (T2) at all crop growth stages. This might be linked to increased phosphorus availability and absorption caused by nano DAP, which promotes root growth and metabolic activity. Seedling dipping provides early nutrient absorption, whereas foliar application at 30 DAT promotes vigorous vegetative development. The synergistic impact of balanced NPK and nano-formulated phosphorus promotes tillering, leaf expansion, and biomass growth. While the number of hills m-2 remained unaffected due to various treatments. Similar patterns were also observed by Deo *et al.* (2022), Poudel *et al.* (2023), Choudhary *et al.* (2024), Maloth *et al.* (2024) and Sahoo *et al.* (2024).

**Table 1:** **Influence of Nano DAP-based Phosphorus application through Seedling Dipping and Foliar Spray on growth attributes of transplanted rice**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **Number of hills (m-2)** | **Plant Height (cm)** | **Number of tillers (m-2)** | **Leaf Area Index** | **Dry Matter Accumulation (g m-2)** |
| T1: Control (0% P + 100% N and K) | 48.15 | 95.95 | 299.56 | 2.95 | 644.74 |
| T2: 100% recommended N: P: K | 49.59 | 113.09 | 409.52 | 4.30 | 1070.75 |
| T3: 75% recommended P + 100% Recommended N and K | 48.61 | 108.45 | 371.15 | 3.62 | 953.59 |
| T4: 50% recommended P + 100% Recommended N and K | 48.28 | 102.11 | 356.76 | 3.30 | 862.57 |
| T5: T3 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 50.11 | 116.93 | 437.99 | 4.48 | 1148.18 |
| T6: T3 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 50.23 | 121.18 | 442.53 | 4.54 | 1170.14 |
| T7: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 48.93 | 104.97 | 378.88 | 3.92 | 1011.54 |
| T8: T4 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 49.03 | 107.40 | 383.81 | 3.95 | 1019.65 |
| T9: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT | 49.80 | 110.21 | 421.09 | 4.33 | 1118.69 |
| T10: T4 + seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT | 49.97 | 111.78 | 424.33 | 4.36 | 1133.73 |
| SEm± | 2.00 | 3.45 | 13.70 | 0.14 | 35.28 |
| CD (P≤0.05) | NS | 10.24 | 40.70 | 0.42 | 104.81 |

3.2 *Effect on Yield attributes*

The crop's sink capacity, or its capacity to accumulate assimilates in grains, is directly influenced by the yield attributes. The yield attributing characters such as number of effective tillers, grains penicle-1, and panicle length were influenced by different treatments of seedling dipping and foliar application of nano-DAP (table 2). Among the different treatments of seedling dipping and foliar application of nano-DAP, 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T6), had resulted in significantly highest yield attributes *viz.,* number of effective tillers (424.15 m-2), grains penicle-1 (104.49), and panicle length (25.76 cm) which was statistically on par with 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T5), 50% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT (T10), 50% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT (T9) and 100% recommended N: P: K (T2) and was significantly superior over the other combined application of seedling dipping and foliar application of nano-DAP.

**Table 2:** **Influence of Nano DAP-based Phosphorus application through Seedling Dipping and Foliar Spray on yield attributes of transplanted rice**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Yield Attributes** | | | |
| **Effective tillers (m-2)** | **Panicle length (cm)** | **No. of Grains Panicle-1** | **Test Weight (g)** |
| T1: Control (0% P + 100% N and K) | 296.72 | 20.05 | 74.11 | 21.17 |
| T2: 100% recommended N: P: K | 392.76 | 23.92 | 95.15 | 23.90 |
| T3: 75% recommended P + 100% Recommended N and K | 356.82 | 22.77 | 87.94 | 22.90 |
| T4: 50% recommended P + 100% Recommended N and K | 342.68 | 22.12 | 83.05 | 22.66 |
| T5: T3 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 418.65 | 25.08 | 101.84 | 24.35 |
| T6: T3 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 424.15 | 25.76 | 104.49 | 24.50 |
| T7: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 371.61 | 23.11 | 92.09 | 23.38 |
| T8: T4 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 376.27 | 23.36 | 92.70 | 23.56 |
| T9: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT | 400.54 | 24.16 | 98.36 | 24.04 |
| T10: T4 + seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT | 405.24 | 24.46 | 98.84 | 24.11 |
| SEm± | 15.59 | 0.81 | 3.34 | 0.90 |
| CD (P≤0.05) | 46.33 | 2.41 | 9.92 | NS |

However, the significantly the lowest yield attributes *viz.,* number of effective tillers (296.72 m-2), grains penicle-1 (74.11), and panicle length (20.05 cm) were observed with the application of 0% P + 100% N and K (control) (T1). The combined effects of a balanced nutrient supply, particularly phosphorus in conjunction with nitrogen and potassium, and nano-DAP administered as a foliar spray and for seedling dipping may be the cause of this. Better root growth, more tillering, and grain filling result from improved nutrient absorption and translocation caused by nano-DAP, which also increases the efficiency of phosphorus usage. Conversely, the lowest values in T1 were caused by phosphorus shortage, which impairs reproductive success, panicle formation, and root growth, leading to subpar yield qualities.

Numerous methods of seedling dipping and foliar application of nano-DAP did not significantly affect the test weight; however, the application of 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T6) produce the highest test weight (24.50 g), followed by the application of treatment 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T5) i.e, (24.35 g) and control (0% P + 100% N and K) produce the lowest test weight (21.17 g). Due to increased phosphorus availability brought about by nano DAP, which boosted seed growth, assimilate translocation, and grain filling. Better grain size and density are ensured by phosphorus, which also promotes ATP synthesis and enzyme activation. During crucial phases of grain development, foliar spraying and seedling dipping offered a steady supply of nutrients. On the other hand, control plots have low phosphorus resulted in inadequate grain filling and a lower test weight. These findings are on the line with those reported by Tarafdar *et al.* (2014), Chavan *et al.* (2019), Sorour *et al.* (2020), Meena *et al.* (2021), Sadati Valojai *et al.* (2021), Deo *et al.* (2022), Poudel *et al.* (2023), Maloth *et al.* (2024) and Sahoo *et al.* (2024).

3.3 *Effect on Yield and harvest index*

Grain, straw, biological yield as well as harvest index were influenced significantly by combinations of seedling dipping and foliar application of nano-DAP (table 3).Significantly higher grain yield (4.22 t ha-1), straw yield (6.08 t ha-1), biological yield (10.30 t ha-1) as well as harvest index (40.98 %) was obtained with application of 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T6) which was statistically similar with the treatment where 75% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT (T5), 50% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT (T10), 50% recommended P + 100% Recommended N and K+ seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT (T9) and 100% recommended N: P: K (T2) were applied, while significantly superior over rest of the treatments. However, the significantly the lowest grain yield (1.92 t ha-1), straw yield (4.86 t ha-1), biological yield (6.77 t ha-1) as well as harvest index (28.27%) were observed with the application of 0% P + 100% N and K (control) (T1). This may be because nano-DAP facilitates better nutrient absorption, particularly phosphorus, which improves photosynthesis, root development, and assimilate partitioning. Better panicle growth, increased grain formation, and effective biomass use resulted from this. Phosphorus shortage, on the other hand, limited energy transfer, tillering, and reproductive development, resulting in the lowest levels in T1. These results are in accordance to the findings of Tarafdar *et al.* (2014), Chavan *et al.* (2019), Patil *et al.* (2020), Sorour *et al.* (2020), Meena *et al.* (2021), Sathyanarayana *et al.* (2021), Sadati Valojai *et al.* (2021), Deo *et al.* (2022), Poudel *et al.* (2023), Maloth *et al.* (2024) and Sahoo *et al*. (2024).

**Table 3:** **Influence of Nano DAP-based Phosphorus application through Seedling Dipping and Foliar Spray on yields and harvest index of transplanted rice**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Yield (t ha-1)** | | | **Harvest Index (%)** |
| **Grain Yield** | **Straw yield** | **Biological Yield** |
| T1: Control (0% P + 100% N and K) | 1.92 | 4.86 | 6.77 | 28.27 |
| T2: 100% recommended N: P: K | 3.79 | 5.63 | 9.42 | 40.20 |
| T3: 75% recommended P + 100% Recommended N and K | 2.98 | 5.22 | 8.19 | 36.32 |
| T4: 50% recommended P + 100% Recommended N and K | 2.62 | 5.08 | 7.69 | 34.00 |
| T5: T3 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 4.07 | 6.03 | 10.10 | 40.28 |
| T6: T3 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 4.22 | 6.08 | 10.30 | 40.98 |
| T7: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 3.33 | 5.39 | 8.72 | 38.22 |
| T8: T4 + seedling dipping with nano DAP @ 5ml litre-1 + Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT | 3.43 | 5.54 | 8.97 | 38.25 |
| T9: T4 + seedling dipping with nano DAP @ 2.5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT | 3.92 | 5.83 | 9.74 | 40.20 |
| T10: T4 + seedling dipping with nano DAP @ 5ml litre-1 + 2 Foliar Spray with nano DAP @ 4 ml litre-1 of water at 30 DAT and 75 DAT | 4.00 | 5.97 | 9.98 | 40.11 |
| SEm± | 0.15 | 0.24 | 0.38 | 0.39 |
| CD (P≤0.05) | 0.44 | 0.70 | 1.12 | 1.16 |

1. **CONCLUSION**

According to one-year experimentation it is concluded that the combined application of 75% recommended P + 100% recommended N and K, seedling dipping in nano-DAP @ 5 ml litre-1, and foliar spray @ 4 ml litre-1 at 30 DAT (T6) greatly improved rice development, yield attributes and overall productivity. T6 outperformed the other treatments but was comparable to T5, T9, T10, and T2. This suggests that rice performance can be enhanced by partially substituting phosphorus with nano-DAP.

**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.

**5. REFERENCES**

Adhikari, T., & Ramana, S. (2019). Nano fertilizer: its impact on crop growth and soil health. *The Journal of Research, PJTSAU*, *47*(3), 1-11.

Al-Khuzai, A. H. G., & Al-Juthery, H. W. A. (2020). Effect of DAP fertilizer source and nano fertilizers (silicon and complete) spray on some growth and yield indicators of rice (*Oryza sativa* L. cv. Anber 33). *IOP Conference Series: Earth and Environmental Science*.

Attri, M., Sharma, N., Mehta, S., & Mecarty, J. S. (2023). Effects of seedling dipping and foliar application of nano dap on growth, yield and economics of fine rice. *Bangladesh Journal of Botany*, 52(4), 1025-1031.

Chavan, Y. S., Chavan, A. P., Rajemahadik, V. A., Warankar, V. V., Chavn, V. G., & Sagavekar, V. V. (2019). Response of Rice to Age of Seedlings, Crop Geometry and Nano-fertilizers in Terms of Yield, Economics, Nutrient Content and Uptake Pattern in Konkan region. *International Journal of Agriculture Sciences*, *11*(18), 9106-9109.

Choudhary, Y. S., Bijarnia, H. K., Saini, C. S., Jat, M. K., Chaturvedi, V., Choudhary, S., Katariya, M., & Choudhary, S. (2024). Effect of Nano fertilizer on growth, yield attributes and yield of Cowpea (*Vigna unguiculata* L.) *African Jornal of Biological Sciences*, *6*(Si4), 5938-5947. <https://doi.org/https://doi.org/10.48047/AFJBS.6.Si4.2024.5938-5947>

Deo, H. R., Chandrakar, T., Srivastava, L. K., Nag, N. K., Singh, D. P., & Thakur, A. (2022). Effect of Nano-DAP on yield, nutrient uptake and nutrient use efficiency by rice under Bastar plateau. *The Pharma Innovation Journal*, *11*(9), 1463-1465.

Ditta, A. (2012). How helpful is nanotechnology in agriculture?. *Advances in Natural Sciences: Nanoscience and Nanotechnology*, *3*(3), 033002.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedures for agricultural research 2nd Edition, a Wiley Inter Science Publications, New York, USA.

Kumari, M. S., Rao, P. C., Padmaja, G., Ramulu, V., Saritha, J. D., & Ramakrishna, K. (2017). Effect of bio and nano phosphorus on yield, yield attributes and oil content of groundnut (*Arachis hypogaea* L.). *Environment Conservation Journal*, *18*(3), 21-26.

Maloth , A., Thatikunta , R., Parida , B. K., Naik, D. S., & Varma, N. R. G. (2024). Evaluation of Nano-DAP on Plant Growth, Enzymatic Activity and Yield in Paddy (*Oryza sativa* L.). *International Journal of Environment and Climate Change*, *14*(1), 890–897. <https://doi.org/https://doi.org/10.9734/ijecc/2024/v14i13907>

Meena, R. H., Jat, G., & Jain, D. (2021). Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of wheat. *Journal of Environmental Biology*, *42*, 302-308. <https://doi.org/http://doi.org/10.22438/jeb/42/2/MRN-1465>

Patil, S. S., Balpande, S. S., Mairan, N. R., Sajid, M., & Ghodpage, R. M. (2020). Influence of integrated nutrient management using nano phosphatic fertilizer on nutrient use efficiency and yield of wheat (Triticum aestivum L.) in Vertisols. *International Journal of Chemical Studies*, *8*(6), 757-762. <https://doi.org/https://doi.org/10.22271/chemi.2020.v8.i6k.10860>

Poudel, A., Singh, S. K., Jiménez-Ballesta, R., Jatav, S. S., Patra, A., & Pandey, A. (2023). Effect of nano-phosphorus formulation on growth, yield and nutritional quality of wheat under semi-arid climate. *Agronomy*, *13*(3), 768. <https://doi.org/https://doi.org/10.3390/agronomy13030768>

Sadati Valojai, S. T., Niknejad, Y., Fallah Amoli, H., & Barari Tari, D. (2021). Response of rice yield and quality to nano-fertilizers in comparison with conventional fertilizers. *Journal of Plant Nutrition*, *44*(13), 1971-1981. <https://doi.org/https://doi.org/10.1080/01904167.2021.1884701>

Sahoo, B. R., Dash, A. K., Mohapatra, K. K., Mohanty, S., Sahu, S. G., Sahoo, B. R., Prusty, M., & Priyadarshini, E. (2024). Strategic management of nano-fertilizers for sustainable rice yield, grain quality, and soil health. *Frontiers in Environmental Science*, *12*, 1420505.

Sathyanarayana, E., Padmaja, G., Sharma, S. H. K., Vidya, G. C., Sagar, S., Bharghavi, J., & Rajashekhar, M. (2021). Effect of different sources and levels of nitrogen, phosphorus and zinc on soil fertility, nutrient content, uptake and yield of soybean. *The Pharma Innovation Journal*, *10*(7), 1152-1156.

Sorour, F. A., Metwally, T. F., El-Degwy, I. S., Eleisawy, E. M., & Zidan, A. A. (2020). The effects of nano phosphatic fertilizer application on the productivity of some Egyptian rice varieties (*Oryza sativa* L.). *Applied Ecology & Environmental Research*, *18*(6), p7673. <https://doi.org/10.15666/aeer/1806_76737684>

Talboys, P. J., Healey, J. R., Withers, P. J. A., Roose, T., Edwards, A. C., Pavinato, P. S., & Jones, D. L. (2020). Combining seed dressing and foliar applications of phosphorus fertilizer can give similar crop growth and yield benefits to soil applications together with greater recovery rates. *Frontiers in Agronomy*, *2*, 605655. <https://doi.org/10.3389/fagro.2020.605655>

Tarafdar, J. C., Raliya, R., Mahawar, H., & Rathore, I. (2014). Development of zinc nanofertilizer to enhance crop production in pearl millet (Pennisetum americanum). *Agricultural Research*, *3*(3), 257-262. <https://doi.org/10.1007/s40003-014-0113-y>

Yoshida S., Cock J.H., and Parao F.T. (1972). Physiological aspects of high yield. Int. Rice Res. Inst. Rice breeding, pp. 455-469

.