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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.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

During the 2024 *kharif* season, a field experiment was carried out at the Agriculture Research Farm of Rama University, Mandhana, Kanpur, Uttar Pradesh, to assess the effects of applying

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phosphorus based on nano DAP via foliar spray and seedling dipping on transplanted rice yield, growth, and yield attributes. Ten treatment combinations made up the trial, which was carried out using a Randomized Complete Block Design (RCBD). The crop was grown using all advised agronomic techniques, and fertilizer was used in accordance with 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 productive 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 can be determined that 25% DAP substitution 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, resulting in a higher yield of transplanted rice.

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.

Utilizing nano materials smaller than 100 nm, nanotechnology is a fascinating topic of study that may present a previously unheard-of chance to create concentrated plant nutrient sources with increased absorption rates, usage efficacy, and reduced losses. Nano fertilizer, which enhances plants' capacity to absorb nutrients, is one of the most significant applications of nanotechnology (Ditta, 2012). In order to create nano fertilizers, plant nutrients are encapsulated in nanomaterials, applied thinly to the nutrients, and then delivered as nanosized emulsions. Higher nutrient usage efficiency (NUE) results from the absorption of nanomaterials and their penetration deep inside plant leaves, which is facilitated by nanopores and stomatal apertures. The plasmodesmata, which are nanoscale (50–60 nm) passageways that connect cells, allow nano fertilizers to transport and supply nutrients more efficiently. Field crops are more productive (6–17%) and have greater nutritional quality due to the increased NUE and noticeably lower nutrient losses with nano fertilizers (Adhikari & Ramana, 2019). In order to boost crop output, enhance quality, and improve the overall sustainability of agricultural systems, nano-fertilizers deliver nutrients to the crop gradually and steadily as needed (Tarafdar et al*.,* 2014).

In order to prevent the overuse and imbalance of Di-ammonium phosphate, the Nano Biotechnology Research Center, in collaboration with Indian Farmers Fertilizers Cooperative Limited, produces the environmentally friendly fertilizer Nano Di-ammonium phosphate in liquid formulations. In its nano form, nano di-ammonium phosphate has a weight percentage of 8% nitrogen and 16% phosphorus. Crop

nitrogen and phosphorus requirements are efficiently met by seedling treatment and foliar application of nano diammonium phosphate (Al-Khuzai & Al-Juthery, 2020). Applying nano-Di-ammonium phosphate to seedlings increases their vigor and encourages root development, both of which increase biomass output (Attri et al*.,* 2023). Additionally, dipping seedlings in nano-Di-ammonium phosphate increases rice grain production by 10 to 50% while reducing applied phosphorus by 40 to 60% (Kumari et al., 2017). But when nano diammonium phosphate is applied topically, it penetrates the leaf through stomatal and cuticular pores, raising the concentration of phosphorus in both the roots and the shoots. This, in turn, speeds up the rice crop's absorption of phosphorus (Talboys et al., 2020). In light of this, the current study was conducted to assess the effects of applying Nano DAP-Based Phosphorus by foliar spraying and seedling dipping on transplanted rice (*Oryza sativa* L.) growth, yield characteristics, and yield.

2. 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 of 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}), medium phosphorus (14.58 kg ha^{-1}), and medium potassium (244.48 kg ha^{-1}). Ten treatments comprising of T_1: Control (0% P + 100% N and K), T_2: 100% recommended N: P: K, T_3: 75% recommended P + 100% Recommended N and K, T_4: 50% recommended P + 100% Recommended N and K, T_5: T_3 + seedling dipping with nano DAP @ 2.5ml $litre^{-1}$ + Foliar Spray with nano DAP @ 4 ml $litre^{-1}$ of water at 30 DAT, T_6: T_3 + seedling dipping with nano DAP @ 5ml $litre^{-1}$ + Foliar Spray with nano DAP @ 4 ml $litre^{-1}$ of water at 30 DAT, T_7: T_4 + seedling dipping with nano DAP @ 2.5ml $litre^{-1}$ + Foliar Spray with nano DAP @ 4 ml $litre^{-1}$ of water at 30 DAT, T_8: T_4 + seedling dipping with nano DAP @ 5ml $litre^{-1}$ + Foliar Spray with nano DAP @ 4 ml $litre^{-1}$ of water at 30 DAT, T_9: T_4 + 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, T_{10}: T_4 + 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. During the years, the rice variety Sarju 52 was cultivated using the suggested agronomic techniques. According to the treatments, urea, DAP, and MOP were used to apply the appropriate dosage of fertilizers, which were 120 kg N, 60 kg P_2O_5, and 60 kg K_2O ha^{-1}. After 15 minutes of dipping rice seedlings in nano DAP solution at 2.5 and 4 milliliters per liter of water, the crop was transplanted in accordance with the treatments. In contrast to a single foliar spray that was administered at 30 DAT alone, two foliar sprays of nano DAP were applied: the first at 30 DAT and the second at 75 DAT (one week before to flowering). At 15 DAT, the initial number of hills m^{-2}, plant height, number of tillers m^{-2}, and accumulation of dry matter were measured at various phases of the rice crop's growth. Using the method provided by Yoshida et al*.* (1972), the leaf area index was calculated.

$$LAI = \frac{Total\ leaf\ area}{Unit\ ground\ area}$$

Where, LAI: Leaf Area Index.

At harvest, traits that contributed to yield were noted, including number of productive tillers, panicle length, grains $panicle^{-1}$, test weight, biological yield, straw yield, and grain yield. The following formula was used to determine the harvest index:

$$\text{Harvest index} = \frac{Grian\ yield}{Biological\ yield} x\ 100$$

Where, biological yield = grain yield + straw yield.

As recommended by Gomez and Gomez (1984), a statistical analysis was performed on the data from a single season. The F test was used to determine statistical significance at the 0.05 level of probability for the critical difference (CD).

3. RESULTS 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 (T_6) 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 (T_5), 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 (T_{10}), 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 (T_9) and 100% recommended N: P: K (T_2) 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).

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 productive tillers, grains $panicle^{-1}$, 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 (T_6), had resulted in significantly highest yield attributes *viz.,* number of productive tillers (424.15 m^{-2}), grains $panicle^{-1}$ (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 (T_5), 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 (T_{10}), 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 (T_9) and 100% recommended N: P: K (T_2) and was significantly superior over the other combined application of seedling dipping and foliar application of nano-DAP.

However, the significantly the lowest yield attributes *viz.,* number of productive 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) (T_1). 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 T_1 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 (T_6) 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 (T_5) 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

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})
T_1: Control (0% P + 100% N and K)	48.15	95.95	299.56	2.95	644.74
T_2: 100% recommended N: P: K	49.59	113.09	409.52	4.30	1070.75
T_3: 75% recommended P + 100% Recommended N and K	48.61	108.45	371.15	3.62	953.59
T_4: 50% recommended P + 100% Recommended N and K	48.28	102.11	356.76	3.30	862.57
T_5: T_3 + 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
T_6: T_3 + 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
T_7: T_4 + 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
T_8: T_4 + 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
T_9: T_4 + 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
T_{10}: T_4 + 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

Table 2. Influence of nano DAP-based phosphorus application through seedling dipping and foliar spray on yield attributes of transplanted rice

Treatments	Yield Attributes			
	Productive tillers (m^{-2})	Panicle length (cm)	No. of Grains $Panicle^{-1}$	Test Weight (g)
T_1: Control (0% P + 100% N and K)	296.72	20.05	74.11	21.17
T_2: 100% recommended N: P: K	392.76	23.92	95.15	23.90
T_3: 75% recommended P + 100% Recommended N and K	356.82	22.77	87.94	22.90
T_4: 50% recommended P + 100% Recommended N and K	342.68	22.12	83.05	22.66
T_5: T_3 + 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
T_6: T_3 + 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
T_7: T_4 + 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
T_8: T_4 + 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
T_9: T_4 + 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
T_{10}: T_4 + 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

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	
T_1: Control (0% P + 100% N and K)	1.92	4.86	6.77	28.27
T_2: 100% recommended N: P: K	3.79	5.63	9.42	40.20
T_3: 75% recommended P + 100% Recommended N and K	2.98	5.22	8.19	36.32
T_4: 50% recommended P + 100% Recommended N and K	2.62	5.08	7.69	34.00
T_5: T_3 + 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
T_6: T_3 + 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
T_7: T_4 + 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
T_8: T_4 + 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
T_9: T_4 + 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
T_{10}: T_4 + 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

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 (T_6) 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 (T_5), 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 (T_{10}), 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 (T_9) and 100% recommended N: P: K (T_2) were applied, while significantly superior over rest of the treatments. However, the significantly lowest grain yield (1.92 t ha^{-1}), straw yield (4.86 t ha^{-1}), biological yield (6.77 t ha^{-1}) and harvest index (28.27%) were observed with the application of 0% P + 100% N and K (control) (T_1). 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 T_1. 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).

4. CONCLUSION

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 (T_6) significantly enhanced rice development, yield attributes, and overall productivity, according to a year's worth of experience. While T_6 was similar to T_5, T_9, T_{10}, and T_2, it fared better than the other tretments. This implies that using nano-DAP to partially replace phosphorus in rice can improve its performance.

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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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