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RESEARCH PAPER

Effect of nano-DAP based nutrient management on growth, yield and economics of *kharif* maize (*Zea mays* L.)

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Abstract: A field experiment was conducted during the *kharif* season to evaluate the effect of nano-DAP based nutrient management on growth, yield and economics of maize (*Zea mays* L.). The results revealed that nutrient management practices significantly influenced crop growth and productivity. Application of 100% recommended dose of N & P (RDNP) recorded superior growth parameters such as plant height and dry matter accumulation and produced the highest grain yield (6.6 t ha^{-1}). Treatments 75% RDNP + 2% DAP foliar spray (FS) at 49 DAS, 75% RDNP + nano-DAP seed treatment (NDAP ST) + foliar spray (2 ml L^{-1} at 33 DAS) and 75% RDNP + nano-DAP seed treatment + foliar spray (4 ml L^{-1} at 33 DAS) also produced comparable yields. Economic analysis indicated that 100% RDNP resulted in the highest gross returns (Rs. 152.1 ×10^{3} ha^{-1}), net returns (Rs. 111.3 × 10^{3} ha^{-1}) and B:C ratio (2.73). Treatments 75% RDNP + 2% DAP FS (49 DAS), 75% RDNP + NDAP ST + FS (2 ml L^{-1} at 33 DAS) and 75% RDNP + NDAP ST + FS (4 ml L^{-1} at 33 DAS) also recorded comparable economic returns. The study indicated that integrating nano-DAP with 75% RDNP sustains maize productivity and profitability, suggesting a potential 25% saving in conventional N&P fertilizer.

Keywords: Economic analysis • Foliar application • Grain yield • Nano-DAP • Nutrient management

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Introduction

Maize (*Zea mays* L.) is one of the most versatile and productive cereal crops globally and serves as an important source of food, feed, fodder, and industrial raw materials. Globally, maize is cultivated on about 206 million hectares with a production exceeding 1.2 billion tonnes and an average productivity of 5.8 t ha^{-1} (FAO, 2023). In India, maize occupies approximately 12.02 million hectares with a production of 42.28 million tonnes and an average productivity of 3.52 t ha^{-1} (GOI, 2025). The crop is often referred to as the "queen of cereals" due to its high yield potential and adaptability to diverse agro-climatic conditions. Despite its importance, maize productivity in India remains lower than the global average, particularly under rainfed *kharif* conditions where about 70% of the area contributes nearly 59% of total production (GOI, 2025). The demand for maize is also increasing due to its growing use in feed and industrial sectors, particularly in poultry feed which accounts for nearly 47% of the total maize consumption in India (FICCI, 2022). Moreover, the advancement of the ethanol blending target (E20) to 2025–26 is expected to substantially increase the demand for maize in the coming years (NAAS, 2024).

Maize is a nutrient-exhaustive crop, particularly when grown as hybrids, and requires adequate nitrogen (N) and phosphorus (P) for optimum growth and productivity. However, the nutrient use efficiency (NUE) of conventional fertilizers is generally low, resulting in significant nutrient losses and environmental concerns (Fazelian and Yousefzadi, 2022). Phosphorus management is especially critical in India due to the limited availability of indigenous phosphate rock and the country's heavy dependence on imported fertilizers. Diammonium phosphate (DAP) is one of the most widely used phosphorus fertilizers in Indian agriculture, yet its efficiency remains low, with less than 35% of nitrogen and about 20% of phosphorus applied being utilized by crops (Solanki *et al*., 2015; Kumar *et al*., 2022). The remaining phosphorus often becomes fixed in soil through precipitation or adsorption reactions, resulting in phosphorus use efficiency of only 10–20% (Wang *et al*., 2012; Roberts and Johnston, 2015).

In recent years, nano-fertilizers have emerged as a promising alternative to improve nutrient delivery and enhance nutrient use efficiency. Among these, nano-DAP is a novel nano-formulation containing 8% nitrogen and 16% phosphorus (P_2O_5) in nano-sized particles that facilitate targeted nutrient delivery and improved crop uptake (IFFCO, 2023). Due to its extremely small particle size and larger surface area, nano-DAP can enhance nutrient absorption, reduce losses, and potentially sustain crop yields with reduced fertilizer application (Raliya *et al.,* 2018; Grillo *et al.,* 2021). Preliminary trials conducted by IFFCO and ICAR institutions indicate that nano-DAP can maintain crop yield with nearly 50% reduction in conventional DAP application (IFFCO, 2022). However, information on the performance of nano-DAP in maize under field conditions, particularly regarding growth, yield, nutrient use efficiency, and soil properties, is still limited.

Therefore, the present investigation entitled "Evaluation of nano-DAP in maize for productivity and profitability" was conducted at the ICAR-Indian Agricultural Research Institute (IARI), New Delhi, during the *kharif* season of 2024.

Materials and methods

A field experiment was conducted during the *kharif* season of 2024 at the Research Farm of the Division of Agronomy, ICAR–Indian Agricultural Research Institute, New Delhi (28.64° N latitude, 77.16° E longitude and 228.6 m above mean sea level). The region has a semi-arid subtropical climate. The experimental soil was sandy loam in texture, slightly alkaline in reaction (pH of 7.67), low in organic carbon (0.46%) and available nitrogen (183 kg ha^{-1}), and medium in available phosphorus (14.5 kg ha^{-1}) and potassium (254 kg ha^{-1}).

The experiment was laid out in a randomized block design with ten treatments and three replications. The treatments consisted of different combinations of recommended dose of nitrogen and phosphorus along with DAP spray and nano-DAP seed treatment and foliar application. The treatments included: T_1 – control (Only RDK); T_2 – 100% recommended dose of N and P; T_3 – 75% recommended dose of N and P + 2% DAP spray at 45–50 DAS; T_4 – 50% recommended dose of N and P + 2% DAP spray at 30–35 and 45–50 DAS; T_5 – 75% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + one foliar spray of nano-DAP @ 2 ml L^{-1} at 30–35 DAS; T_6 – 75% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 4 ml L^{-1} at 30–35 DAS; T_7 – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 2 ml L^{-1} at 30–35 DAS; T_8 – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 4 ml L^{-1} at 30–35 DAS; T_9 – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 2 ml L^{-1} at 30–35 and 45–50 DAS; and T_{10} – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 4 ml L^{-1} at 30–35 and 45–50 DAS.

The recommended dose of nutrients was 150:60:40 kg N: P_2O_5: K_2O ha^{-1} (equivalent to 150:26.2:33.3 kg N: P: K ha^{-1}). Nitrogen was supplied through urea, phosphorus through di-ammonium phosphate (DAP), and potassium through muriate of potash (MOP). Potassium was applied as basal in all treatments, while nitrogen and phosphorus were applied as per treatment combinations. Foliar sprays were applied using a knapsack sprayer with a spray volume of 500 L ha^{-1} at 30–35 DAS and 600 L ha^{-1} at 45–50 DAS.

Maize hybrid Pusa HQPM-5 Improved was sown at a spacing of 60 cm × 20 cm following standard agronomic practices. Weed control was achieved through pre-emergence application of atrazine (0.5 kg ha^{-1}), followed by post-emergence application of tembotrione (120 g ha^{-1}) at 20–25 DAS (3–4 leaf stage of maize). Other crop management practices were followed as per the recommended package of practices for maize.

Growth observations such as plant height, leaf area index (LAI) and dry matter accumulation were recorded from five randomly selected plants in each plot at different growth stages. Biological yield, cob yield, stover yield and grain yield were was obtained from each plot and converted to kg ha^{-1} at standard moisture content. Shelling percentage and harvest index were calculated.

LAI was calculated with following mathematical expression (Watson, 1947).

$$\text{LAI} = \frac{\text{Total leaf area per plant (cm}^2\text{)}}{\text{Land area per plant (cm}^2\text{)}}$$

Leaf area was measured using a digital leaf area meter. The total leaf area per plant was obtained by summing individual leaf areas. The economic analysis was determined as follows:

Net returns = (Gross returns) – (Cost of cultivation)

$$\text{Benefit-Cost Ratio} = \frac{\text{Net returns}}{\text{Total cost of cultivation}}$$

Statistical analysis

The recorded data were subjected to analysis of variance (ANOVA) for a randomized block design using OPSTAT software, and treatment means were compared using the least significant difference (LSD) test at the 5% probability level.

Results and discussion

Growth attributes

Plant height of maize was significantly affected by different nutrient management practices at all growth stages (Table 1). Plant height was consistently highest under 100% RDNP throughout the crop growth period. Treatments T_3 (75% RDNP + 2% DAP foliar spray at 45–50 DAS) and T_6 (75% RDNP + nano-DAP seed treatment + foliar spray @ 4 ml L^{-1} at 30–35 DAS) remained statistically at par with the superior treatment (T_2: 100% RDNP) at most growth stages, whereas the lowest plant height was recorded in T_1 (control: only RDK). The increased plant height under these treatments may be attributed to improved nutrient availability, particularly nitrogen and phosphorus, which stimulate cell division, elongation, and chlorophyll synthesis. Foliar application of nano-DAP likely improved phosphorus use efficiency during rapid vegetative growth, sustaining higher photosynthetic activity. These results are in agreement with Tomar *et al.* (2024), who observed that nano-fertilisers enhanced plant height and growth indices in maize by improving nutrient absorption and utilisation efficiency.

Similarly, leaf area index of maize was significantly influenced by different nutrient management practices at all growth stages (Table 1). The highest LAI was recorded with 100% RDNP at 30 DAS (2.30), 60 DAS (5.49), and 90 DAS (4.63). Treatments 75% RDNP + 2% DAP foliar spray (T_3) and 75% RDNP + nano-DAP seed treatment with foliar spray (T6) remained statistically at par with the superior treatment at most stages. The lowest LAI was observed under only RDK. The enhancement of LAI under nano-DAP treatments may be attributed to improved phosphorus availability and utilisation efficiency, which promote leaf expansion, chlorophyll content, and overall photosynthetic area. Nano-fertilisers are known to enhance nutrient uptake efficiency and prolong nutrient availability, thereby improving canopy development and photosynthetic capacity. Similar findings have been reported by Reddy *et al.* (2025) and Tomar *et al*. (2024), who observed increased LAI and chlorophyll content in maize with nano-phosphorus application. Dimkpa and Bindraban (2018) highlighted that nano-fertilisers improve nutrient use efficiency and plant physiological processes, leading to better canopy architecture and biomass production. This is particularly important at mid-growth stages when maize requires maximum photosynthetic efficiency to support biomass accumulation and reproductive growth. The findings indicate that nano-DAP, when applied in combination with reduced RDNP, can sustain canopy vigour comparable to full RDNP, thereby demonstrating potential for fertiliser saving. These findings align with those of Reddy *et al.* (2025), who reported that nano-phosphorus fertilisers significantly improved leaf area index and photosynthetic activity in maize, leading to enhanced biomass productivity.

Dry matter accumulation varied significantly among nutrient management treatments (Table 1). Overall, higher biomass production was associated with treatments receiving adequate nitrogen and phosphorus. The 100% RDNP treatment (T_2) showed superior dry matter accumulation during early growth stages, whereas at later stages, T_6 (75% RDNP + nano-DAP seed treatment + foliar spray @ 4 ml L^{-1}) recorded the highest values, remaining statistically comparable with T_3 (75% RDNP + 2% DAP foliar spray) and T_2. In contrast, T_1 (only RDK) consistently resulted in the lowest dry matter accumulation

Table 1. Effect of nano-DAP application on the growth attributes of *kharif* maize at various growth stages

Treatments*	Plant height (cm)			Leaf area index			Dry matter accumulation (g/m^2)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1: Only RDK	48.4	163.7	160.6	1.15	3.80	2.98	162	482	866
T_2: 100% RDNP	70.0	234.4	252.3	2.30	5.49	4.63	270	807	1437
T_3: 75% RDNP + 2% DAP FS (49 DAS)	59.3	225.4	238.5	2.08	5.47	4.45	245	657	1471
T_4: 50 % RDNP + 2% DAP FS (33 & 49 DAS)	56.4	219.0	229.0	1.67	5.14	3.74	174	504	964
T_5: 75% RDNP + NDAP ST + FS 2ml L^{-1} (33 DAS)	57.4	217.3	227.7	1.74	4.92	4.21	224	618	1241
T_6: 75% RDNP + NDAP ST + FS 4ml L^{-1} (33 DAS)	56.9	223.4	234.1	2.17	4.84	4.52	249	529	1526
T_7: 50% RDNP + NDAP ST + FS 2ml L^{-1} (33 DAS)	56.3	211.5	223.4	1.52	5.10	3.69	205	660	999
T_8: 50% RDNP + NDAP ST + FS 4ml L^{-1} (33 DAS)	55.8	210.9	221.4	1.63	5.42	3.83	166	521	1316
T_9: 50% RDNP + NDAP ST + 2FS 2ml L^{-1} (33 & 49 DAS)	53.4	213.0	224.9	1.76	4.98	3.80	187	675	1001
T_{10}: 50% RDNP + NDAP ST + 2FS 4ml L^{-1} (33 & 49 DAS)	57.8	213.1	223.9	1.62	5.09	3.95	185	621	1161
SEm±	3.59	7.22	7.01	0.081	0.243	0.088	8.8	26.9	70.0
LSD (P=0.05)	10.67	21.44	20.83	0.240	0.722	0.261	26.2	79.8	207.9

*DAS: days after sowing; FS: foliar spray; NDAP ST: seed treatment with nano-DAP; FS: one foliar spray; 2FS: two foliar spray of nano-DAP at 33 & 49 DAS; Recommended K was applied to in all treatments; Recommended dose of fertilizer: RDF ($N:P_2O_5:K_2O$-150:60:40 kg ha^{-1}) was applied; RDK: recommended dose of potassium; RDNP: recommended dose of nitrogen and phosphorus; Seed treatment was done with nano-DAP @ 5 ml kg^{-1} seed.

throughout the crop growth period. The improved performance under nano-DAP treatments may be attributed to better nutrient availability, enhanced nutrient-use efficiency, and improved photosynthetic activity, which promoted greater biomass accumulation. Similar findings were reported by Solanki *et al.* (2015).

Yields

Yield of maize was significantly influenced by different nutrient management practices (Table 2). The highest grain yield was recorded with 100% RDNP (6.6 t ha^{-1}), which remained statistically at par with 75% RDNP + NDAP ST + FS 4 ml L^{-1} (6.3 t ha^{-1}), 75% RDNP + 2% DAP FS (6.2 t ha^{-1}) and 75% RDNP + NDAP ST + FS 2 ml L^{-1} (6.1 t ha^{-1}). This clearly demonstrates that reduced doses of nitrogen and phosphorus, when supplemented with nano-DAP seed treatment and foliar sprays, can sustain yields comparable to the full recommended dose. The enhanced performance of nano-DAP-based treatments may be attributed to improved nutrient solubility, efficient uptake, and prolonged availability during the critical reproductive phase of maize. A similar trend was observed for cob, stover and biological yields, where 100% RDNP (7.4, 8.7 and 16.1 t ha^{-1}, respectively) remained statistically comparable with 75% RDNP + NDAP ST + FS 4 ml L^{-1} (7.3, 8.5 and 15.8 t ha^{-1}). However, treatments with 50% RDNP generally recorded lower yields. The improvement in cob yield under these treatments is likely linked to better nutrient uptake and enhanced source–sink relationships, resulting in increased cob size and grain setting. Treatments with higher stover yields also showed higher biological yields, confirming the role of nutrient availability in enhancing vegetative and reproductive growth simultaneously as similar find also reported by Reddy *et al*. (2025). The highest shelling percentage (95%) was recorded under 50% RDNP + 2% DAP FS, while harvest index did not differ significantly among treatments. The lowest yields were recorded under Only RDK (control). Overall, 75% RDNP combined with nano-DAP seed treatment and foliar spray (T_6) produced yields comparable to 100% RDNP (T_2), indicating enhanced nutrient-use efficiency and effective phosphorus utilisation. This finding has important practical implications, as it suggests that a portion of conventional fertiliser inputs can be reduced without compromising crop productivity. The integration of nano-DAP not only improves nutrient availability and uptake efficiency but also minimises nutrient losses, thereby enhancing fertiliser use efficiency. Such an approach can

Table 2. Effect of nano-DAP application on the grain, cob, stover and biological yield, shelling percentage and harvest index of *kharif* maize

Treatment*	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Cob yield (t ha^{-1})	Biological yield (t ha^{-1})	Shelling (%)	Harvest index (%)
T_1: Only RDK	2.4	6.5	4.0	10.5	61.7	23.1
T_2: 100% RDNP	6.6	8.7	7.4	16.1	90.3	41.2
T_3: 75% RDNP + 2% DAP FS (49 DAS)	6.2	8.2	6.7	14.8	92.6	41.7
T_4: 50 % RDNP + 2% DAP FS (33 & 49 DAS)	5.3	6.9	5.6	12.5	95.0	42.8
T_5: 75% RDNP + NDAP ST + FS 2ml L^{-1} (33 DAS)	6.1	8.0	6.5	14.5	92.7	41.8
T_6: 75% RDNP + NDAP ST + FS 4ml L^{-1} (33 DAS)	6.3	8.5	7.3	15.8	87.5	40.1
T_7: 50% RDNP + NDAP ST + FS 2ml L^{-1} (33 DAS)	4.7	6.4	4.9	11.4	94.7	41.1
T_8: 50% RDNP + NDAP ST + FS 4ml L^{-1} (33 DAS)	4.8	6.6	5.1	11.7	94.6	41.3
T_9: 50% RDNP + NDAP ST + 2FS 2ml L^{-1} (33 & 49 DAS)	5.4	6.5	6.5	13.1	83.6	41.8
T_{10}: 50% RDNP + NDAP ST + 2FS 4ml L^{-1} (33 & 49 DAS)	5.7	6.6	6.5	13.1	87.4	43.3
SEm±	0.22	0.36	0.21	0.39	4.31	2.11
LSD (P=0.05)	0.65	1.08	0.63	1.15	12.82	6.28

*DAS: days after sowing; FS: foliar spray; NDAP ST: seed treatment with nano-DAP; FS: one foliar spray; 2FS: two foliar spray of nano-DAP at 33 & 49 DAS; Recommended K was applied to in all treatments; Recommended dose of fertilizer: RDF (N:P_2O_5:K_2O-150:60:40 kg ha^{-1}) was applied; RDK: recommended dose of potassium; RDNP: recommended dose of nitrogen and phosphorus; Seed treatment was done with nano-DAP @ 5ml/kg seed.

contribute to reducing input costs for farmers and lowering the environmental footprint associated with excessive fertiliser application. Therefore, the combined use of reduced RDNP with nano-DAP offers a sustainable nutrient management strategy for maize cultivation.

Economics

The economics of *kharif* maize was significantly influenced by different nutrient management treatments (Figure 1). Among the treatments, T_2 (100% RDNP) recorded the highest gross returns (Rs. 152.1 × 10^3 ha^{-1}), net returns (Rs. 111.3 × 10^3 ha^{-1}), and benefit–cost ratio (2.73). Treatments T_3 (75% RDNP + 2% DAP foliar spray at 49 DAS), T_5 (75% RDNP + nano-DAP seed treatment + foliar spray @ 2 ml L^{-1} at 33 DAS), and T_6 (75% RDNP + nano-DAP seed treatment + foliar spray @ 4 ml L^{-1} at 33 DAS) were statistically at par with T_2 in terms of gross and net returns. However, treatments involving 50% RDNP combined with nano-DAP applications recorded comparatively lower economic returns. The lowest profitability was observed in T_1 (only RDK), which recorded gross returns of Rs. 57.4 × 10^3 ha^{-1}, net returns of Rs. 22.1 × 10^3 ha^{-1}, and a benefit–cost ratio of 0.63. Overall, application of 100% RDNP or 75% RDNP integrated with foliar spray of DAP or nano-DAP improved economic returns and profitability of *kharif* maize compared with reduced fertilizer dose. Similar findings were noticed by Reddy *et al.* (2025), Kumar and Dahiya (2024), Kumar *et al.* (2022), Sachin *et al.* (2024) and Attri *et al.* (2023).

Conclusion

The present study demonstrated that nutrient management practices significantly influenced the growth, yield and economics of kharif maize. Application of 100% recommended dose of nitrogen and phosphorus (RDNP) produced the highest growth parameters, grain yield (6.6 t ha^{-1}) and economic returns. However, treatments involving 75% RDNP integrated with nano-DAP seed treatment and foliar spray or 2% DAP foliar spray produced statistically comparable yields and economic returns. This indicates that partial substitution of conventional phosphorus fertilizer with nano-DAP can effectively sustain crop productivity. The improved performance under nano-DAP treatments may be attributed to enhanced nutrient availability and improved phosphorus use efficiency. Therefore, application of 75% RDNP along with nano-DAP seed treatment and foliar spray can be considered a promising nutrient management strategy for sustaining maize productivity while reducing conventional fertilizer use.

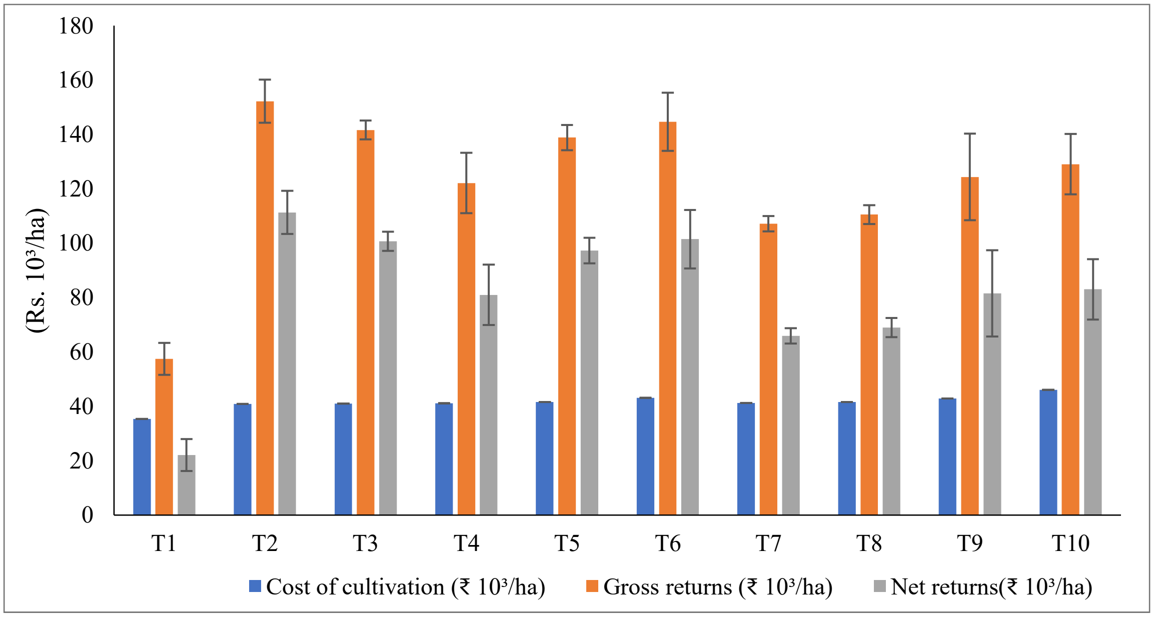

Figure 1. Effect of nano-DAP application on the economics of maize (Cost of cultivation; Gross returns; Net returns) (T_1 – control (Only RDK); T_2 – 100% recommended dose of N and P; T_3 – 75% recommended dose of N and P + 2% DAP spray at 45–50 DAS; T_4 – 50% recommended dose of N and P + 2% DAP spray at 30–35 and 45–50 DAS; T_5 – 75% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + one foliar spray of nano-DAP @ 2 ml L^{-1} at 30–35 DAS; T_6 – 75% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 4 ml L^{-1} at 30–35 DAS; T_7 – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 2 ml L^{-1} at 30–35 DAS; T_8 – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 4 ml L^{-1} at 30–35 DAS; T_9 – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 2 ml L^{-1} at 30–35 and 45–50 DAS; and T_{10} – 50% recommended dose of N and P + seed treatment with nano-DAP @ 5 ml kg^{-1} seed + foliar spray of nano-DAP @ 4 ml L^{-1} at 30–35 and 45–50 DAS).

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