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RESEARCH ARTICLE

Efficacy of Nano DAP as a supplement to conventional phosphorus and its impact on roots, yield and economics

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Abstract

A field study was conducted in 2022 at the College of Agriculture, Navile, Shivamogga, to assess the effects of conventional DAP and nano DAP seed priming and foliar applications on maize growth, root traits and yield. The experiment followed a Randomized Complete Block Design (RCBD) with 11 treatments, including conventional DAP and nano DAP applications, replicated thrice. The combined application of 75 % of the recommended dose of phosphorus (RDP) with nano DAP seed priming and two foliar sprays resulted in a 5.15 % yield increase over the standard Package of Practice (PoP). However, nano DAP applied solely through seed priming and foliar sprays improved yield by 42.26 % over the absolute control but reduced grain yield by 27.08 % compared to PoP. Despite lower phosphorus usage, the combined nano DAP approach significantly enhanced maize growth, root development, yield attributes and nutrient efficiency over conventional phosphorus treatments. This strategy improved crop performance and promoted sustainable phosphorus management by reducing application rates by 25 %, highlighting nano DAP as a promising alternative to traditional fertilization.

Keywords: DAP; foliar spray; nano; priming; RDP

Introduction

Maize relies heavily on essential soil nutrients like nitrogen (N), phosphorus (P) and potassium (K) to support its optimal growth and development (1-3). Nitrogen plays a crucial role in protein synthesis and is a vital component of chlorophyll, instrumental in photosynthesis (4). the sensitivity of maize to phosphorus availability arises from its substantial requirement for this nutrient to support crucial physiological processes (5-7). Phosphorus (P) is maizes' second most essential nutrient after nitrogen, playing a vital role in crop growth and yield (8, 9). Phosphorus plays a pivotal role in numerous physiological processes, serving as a critical component in osmo-regulation and enzyme activation within diverse metabolic pathways and facilitating photosynthesis and the transport of assimilates (10). Approximately 10-25 % of the applied phosphorus becomes accessible to crops, while the remaining portion in the soil enriches the soil phosphorus pool and undergoes conversion into insoluble forms (11). Innovative and futuristic agricultural technologies must be implemented to achieve global food security and enhance plant productivity (12). To improve crop phosphorus use efficiency, nanotechnology has emerged as a revolutionary strategy among various strategies in recent times.

The nano-fertilizers created through advanced nanotechnology are characterized by their reduced size and expanded surface area, resulting in heightened absorption capacity and precise controlled release of nutrients to specific targeted sites (13). The higher surface tension of nanomaterials in priming helps retain nutrients, enabling controlled release to meet soil and crop needs, preventing rapid dissolution and minimizing losses (14). Nanotechnology-based fertilizers can function as plant growth catalysts, facilitating improved gas exchange and root efficiency. Their controlled and gradual nutrient release enhances nutrient accessibility within the root zone (15). Dense and cluster roots help in P availability to plants by increasing the exploration surface area, intense root exudations and microbial attractions (16). Nano-sized nutrients penetrate seed coats efficiently, aiding precise nutrient delivery during germination. Foliar application promotes the direct entry of nutrients into the plant system, thus reducing fertilizer wastage and correcting nutrient deficiencies. Hence, the foliar application of nano fertilizers leads to higher nutrient use efficiency (17), which is why the current study intends to evaluate the efficacy of nano-DAP in growing, rooting and yielding maize . The application of nano DAP in foliar form 6 mL L^{-1} alongside a basal application of nutrients significantly boosted pigeon pea growth and yield (18). Nano DAP combined with phosphate-solubilizing bacteria significantly improved chickpeas' nutrient use efficiency and yield. Also, enhanced root growth and pod filling were reported by previous studies (19). Rice grown with nano DAP foliar application recorded a 15 % increase in yield compared to conventional methods (20). Nano DAP demonstrated better nutrient absorption in wheat, leading to higher biomass production and yield than traditional fertilizers (21). A long-term study on chickpeas showed higher nitrogen fixation and phosphorus uptake with nano DAP application. Enhanced yield stability was recorded under fluctuating weather conditions, which was noted when applying nano fertilizers (22). Keeping the above facts in view, the present investigation was carried out to study its efficacy with a combination of conventional DAP along with nano DAP as seed priming and foliar spray on maize growth and development.

Materials and Methods

Experiment site characteristics

The experiment was conducted at the research farm of the College of Agriculture, Navile, Shivamogga, Karnataka, during Kharif 2022 using a Randomized Complete Block Design (RCBD) with 11 treatment combinations, each replicated thrice. The soil was dried, powdered, sieved (2 mm) and analyzed for physical and chemical properties. It was sandy loam, acidic (pH 5.79), with low electrical conductivity (EC 0.265 dS m^{-1}) and organic carbon (4.51 g kg^{-1}). The available N: P_2O_5:K_2O levels were 119.2:28.8:114.2 mg/kg of soil. The recommended fertilizer application was 150:75:40 kg N, P, K per hectare, with a plant spacing of 60 cm × 30 cm. Nano DAP was procured from The Energy and Resources Institute (TERI), TERI-Deakin Nanobiotechnology Centre, New Delhi, India. It contained 8 % nano nitrogen and 16 % nano phosphorus, with a 20-100 nm particle size.

Treatment details

Treatment details of this study are given below : -

T_1 : RDP (PoP)

T_2 : RDP + SP with conventional DAP at 2 %

T_3 : RDP + SP with nano DAP

T_4 : 75 % RDP + SP with nano DAP

T_5 : 75 % RDP + foliar sprays of nano DAP

T_6 : 75 % RDP + SP with nano DAP + foliar sprays of nano DAP

T_7 : 50 % RDP + SP with nano DAP

T_8 : 50 % RDP + foliar sprays of nano DAP

T_9 : 50 % RDP + SP with nano DAP + foliar sprays of nano DAP

T_{10} : 0 % RDP + SP with nano DAP + foliar sprays of nano DAP

T_{11} : Absolute control

RDF - 150: 75: 40: 10 kg N: P: K: $ZnSO_4$ ha^{-1};Nano DAP seed priming and foliar spray at 2.5 mL L^{-1}, it contains 200 ppm of nano nitrogen and 400 ppm of nano phosphorus, 2 foliar sprays at 30 and 60 days after sowing (DAS)

Seed priming process

The seeds were primed with the nano DAP solution at 2.5 mL L^{-1} in the seed-to-solution ratio of 1:2 (w/v) for 24 hr (23). Then, seeds were kept for shade drying for 24 hr and sowing was taken.

Observation recorded

The data were recorded for growth observations, *i.e.,* seedling vigour index, plant height, leaf area, leaf area index and dry matter production. Root parameters, such as root dry weight and root volume, were determined using the water displacement method (24). Yield parameters and nutrient efficiencies were also determined.

Statistical analysis

The data were statistically analyzed through ANOVA (Analysis of variance) using RCBD, Microsoft Excel and OPSTAT (Operational statistics) and correlation and regression were done using R software. Crop data were subjected to the least significant difference at a probability level ≤ 0.05.

Results

Morphological characters

The growth parameters, including seedling vigour index, plant height, leaf area, leaf area index and dry matter production, were significantly influenced by varied combined agronomic applications of conventional DAP with nano DAP seed priming (SP) and foliar sprays, as well as the control treatment, as indicated in Table 1. Maize plant height exhibited notable variation across different growth stages, with treatment T_6 (75 % RDP + SP with nano DAP + foliar sprays of nano DAP) achieving the highest plant height (161.43 cm), followed by T_3 (159.27 cm), which was statistically comparable to T_9 (143.27 cm). Treatment T_6 also produced the highest dry matter per plant (251.47). Furthermore, T_6 showed the best leaf area and leaf area index performance, recording an area of 4415.70 cm^2 and an index of 3.27, surpassing all other treatments.

Root growth

The seed priming significantly impacted maize root growth, as shown in Fig. 1. The most significant root volume and dry weight were recorded in T_3 (RDP + SP with nano DAP) at all the stages (30, 60 and 90 DAS), which was followed by T_6 (75 % RDP + SP with nano DAP + foliar sprays of nano DAP). In contrast, the control treatment, which did not apply any fertilizer, measured the lowest root growth. Seed-primed treatments improved compared to non-seed-primed ones with the same level of conventional DAP.

Yield and yield attributes

The results of the variance analysis showed that both conventional and nano DAP fertilizer applications significantly influenced yield attributes, as indicated in Table 2. The highest yield was 6254 kg ha^{-1} at T_6 (75 % RDP + SP with nano DAP + foliar sprays of nano DAP), followed by T_3 (6125 kg ha^{-1}). The sole application of nano DAP as seed priming and foliar spray (T_{10}) yielded 4302 kg ha^{-1}. Yield attributes varied significantly, i.e., number of grains per cob, cob weight and cob length and the highest result was T_6. Straw yield ranges from 4385 kg ha^{-1} (T_{11}) to 7716 kg ha^{-1} (T_6).

Economics

The economic analysis (Table 3) indicated that positive higher net returns (73553 Rs. ha^{-1}) in T_6 (75 % RDP + SP with nano DAP + foliar sprays of nano DAP), with a favourable benefit-cost (BC) ratio (2.14), followed by T_3 net returns (73454 Rs. ha^{-1}) and higher

Table 1. Effect of combined application of conventional and nano DAP seed priming and foliar application on maize growth parameter

Treatments	Seedling vigour index- I	Plant height (cm) at harvest	Number of leaves at 90 DAS	Leaf area (cm^2) at 90 DAS	Leaf area index 90 DAS	Plant dry weight (g $plant^{-1}$)
T_1	4954	154.13	13.80	4267.58	3.16	240.59
T_2	5405	155.80	13.87	4280.70	3.17	242.43
T_3	5651	159.27	14.03	4305.79	3.19	246.83
T_4	5554	144.79	13.07	3985.13	2.95	230.52
T_5	4913	153.47	13.77	4247.37	3.15	238.86
T_6	5663	161.43	14.13	4415.70	3.27	251.47
T_7	5496	141.40	12.57	3818.77	2.83	213.96
T_8	4684	143.10	12.63	3939.06	2.92	222.05
T_9	5542	143.27	12.87	3980.84	2.95	226.53
T_{10}	4608	134.63	12.23	3441.12	2.55	184.35
T_{11}	3731	128.93	11.80	2307.06	1.71	133.37
S. Em. ±	108	5.61	0.31	138.95	0.10	4.29
CD (P = 0.05)	320	16.67	0.92	412.78	0.31	12.74

DAS: days after sowing; Seedling vigour index- I = Standard germination (%) × (Shoot length + Root length); S. Em.: Standard error of mean; CD (P = 0.05): critical difference at probability 5 %)

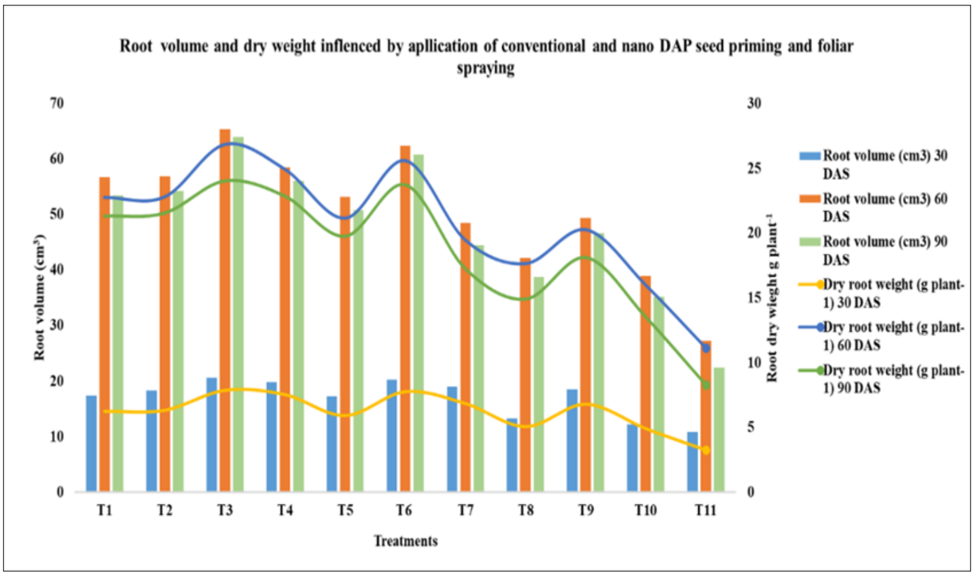

Fig. 1. Influence of combined application of conventional and nano DAP seed priming and foliar application on maize root volume and dry root weight at 30, 60 and 90 days after sowing.

Table 2. Effect of combined application of conventional and nano DAP seed priming and foliar application on maize yield and yield parameters

Treatments	Number of grains cob^{-1}	Cob weight (g)	Cob length (cm)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_1	455.72	130.36	15.96	5900	7466
T_2	460.92	131.18	15.99	5970	7499
T_3	471.60	134.53	16.29	6125	7588
T_4	438.62	121.88	15.88	5648	7159
T_5	456.53	128.89	15.91	5890	7380
T_6	480.28	136.19	16.36	6254	7716
T_7	405.89	114.56	14.86	5158	6729
T_8	413.92	117.12	15.05	5291	7045
T_9	426.11	121.26	15.12	5510	7075
T_{10}	338.83	93.86	14.39	4302	5939
T_{11}	239.29	71.19	11.74	3024	4385
S. Em. ±	15.89	4.33	0.34	201	295
CD (P = 0.05)	47.19	12.85	1.01	598	876

S. Em.: Standard error of mean; CD (P = 0.05): critical difference at probability 5 %)

BC ratio (2.18). However, solely applying nano DAP as seed priming and foliar spray (T_{10}) had only net returns of 38602 Rs. ha^{-1} with a 1.67 BC ratio, which was only above the T_{11} (19696 Rs. ha^{-1}). The BC ratio varies from 1.41 (T_{11}) to 2.18 (T_3).

Table 3. Effect of combined application of conventional and nano DAP seed priming and foliar application on maize economics

Treatments	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C
T_1	130781	69274	2.13
T_2	131568	69732	2.13
T_3	135593	73454	2.18
T_4	125195	65212	2.09
T_5	130472	66539	2.04
T_6	138429	73553	2.14
T_7	114534	56736	1.98
T_8	117624	56117	1.91
T_9	122230	60104	1.97
T_{10}	95854	38602	1.67
T_{11}	67593	19696	1.41

B:C-Benefit cost ratio

Discussions

Combining conventional and nano DAP as seed primers enhanced early crop stages, making these nutrients more accessible to the plant and improving seedling vigour index-I (Table 1). Furthermore, foliar application of nano DAP at 30 and 60 DAS provided an immediate nitrogen and phosphorus supply, boosting plant growth. The plant height of rice increased when nano fertilizer was applied in combination with conventional fertilizers (25-28). Additionally, more leaf area growth and LAI (Leaf area index) helps in light interception and photosynthesis (18, 29) and growth (30). Nano DAP application enhances dry matter accumulation, with a marked increase observed during the reproductive phase. Nitrogen and phosphorus are components of many proteins, amino acids, growth hormones and enzymes that help increase the production and translocation of photosynthates from source to sink (31).

The nano DAP as seed priming enhanced root development due to improved phosphorus availability and nutrient synergy, which promotes better root growth and plant performance (19, 32). Its nanoscale formulation improves the absorption of both nutrients, leading to more efficient root growth (33). Nano nitrogen and phosphorus facilitate phosphorus-containing enzyme activity and protein transport through several mechanisms, enhancing root parameters (34).

The kernel and stover yield result reflects the effectiveness of the combined approach. This synergistic effect achieved by soil application of conventional DAP and seed priming nano DAP during the initial stage of the crop resulted in improved root establishment and increased foliar growth, creating an ideal foundation for efficient absorption of foliar-applied nano DAP. The dual nutrient release and enhanced nutrient availability, efficient photosynthate translocation, improving grain traits and grain yield (25, 28-36). Seed priming and foliar application promote optimal growth, root establishment and nutrient absorption (37), leading to higher yield and yield attributes (26, 35, 36).

Applying nano phosphorus fertilizer led to substantial increases in straw and seed yields (33). However, the sole supply of nano DAP treatment achieved a yield above the control. This showed that only nano DAP could supply the entire nutrient requirement of the maize plant. Furthermore, the regression and correlation analysis (Fig. 2) revealed that these growth and root characters collectively explained a substantial proportion of the variation in yield (Table 2). A similar result was seen in wheat, where the use of nano-phosphorus provided better nutrient accumulation and increased growth activity due to the smart delivery system of the fertilizers (25, 36, 38).

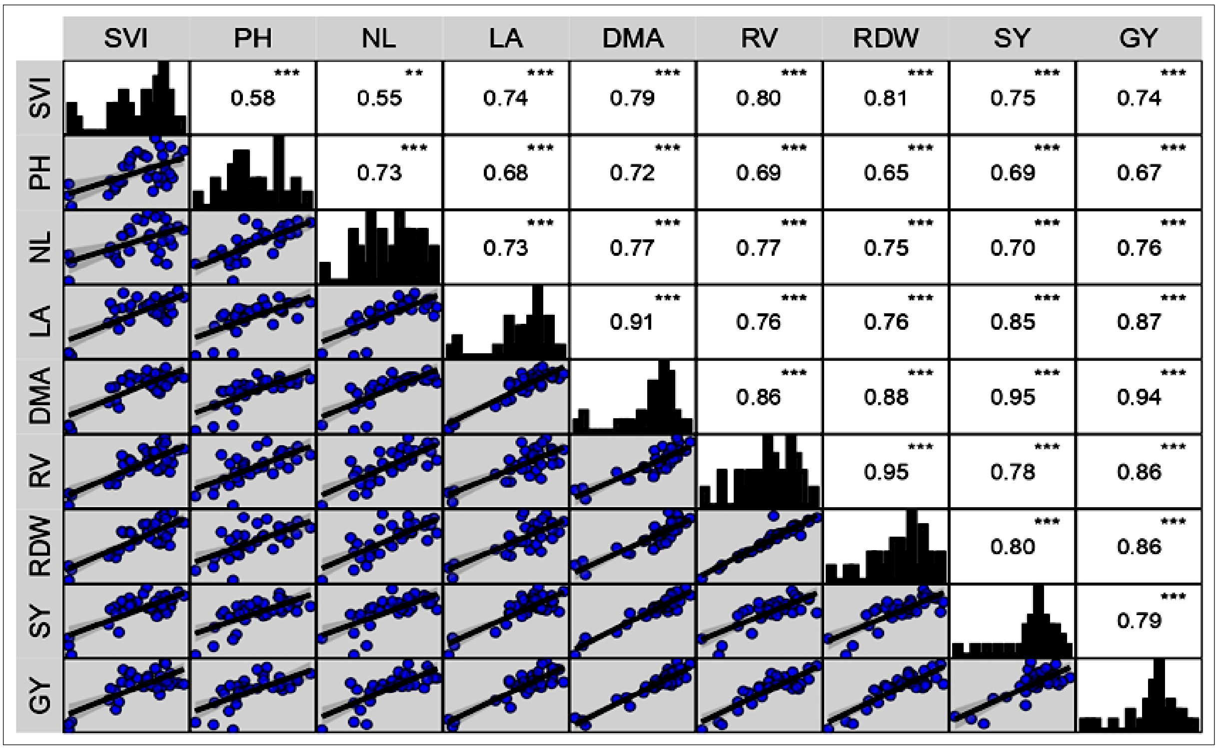

Fig. 2. Multiple correlations and regression matrix among growth, root characters on yield, as influenced by combined application of conventional and nano DAP seed priming and foliar application on maize (SVI: Seedling vigour index- I; PH: plant height; NL: number of leaves; LA: leaf area; DMA: dry matter accumulation; RV: root volume: RDW: root dry weight; SY: stover yield; GY: grain yield; Observation per variable: 33).

The combined nutrient supply approach yielded the highest net returns due to higher grain yield over other treatments. The higher BC ratio in T_3 (Table 3) was due to good grain yield with the lesser cost of cultivation, mainly cost not incurred on 2 foliar sprays and nano DAP nutrient. Research indicates cost savings from reduced fertilizer use and increased income due to higher yields (39). Crops like cotton and vegetables were especially profitable with nano DAP (40).

Conclusion

This study highlighted the efficacy of combining conventional DAP with nano DAP to enhance the growth and development of maize. The results demonstrated that this combined approach improves key growth parameters and contributes to higher yields compared to conventional practices alone. However, the sole application of nano DAP yields resulted only marginally above the control. This suggests that while nano DAP has potential benefits, it cannot independently fulfil the complete nutrient requirements of maize plants. Therefore, relying solely on nano DAP may not be sufficient for optimal maize production. Integrating nano DAP with conventional fertilizers is a promising avenue for improving maize productivity while minimizing environmental risks associated with overfertilization.

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Authors' contributions

MLS planned and designed the research study, conducted the experiments, performed statistical analysis and drafted the manuscript. HKV also planned the study, carried out the experiments, contributed to the conceptualization and statistical analysis and reviewed the manuscript. SSD was involved in statistical analysis and assisted in drafting the manuscript. NEN contributed to data analysis and supported manuscript drafting. HDS participated in conceptualizing the study and reviewing the manuscript. SKA contributed to the conceptualization of the research and helped in reviewing the final draft. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None

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