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Optimization of Nano-DAP Fertilization for Improvement in Growth and Yield of Finger Millet (*Eleusine coracana* (L.) Gaertn.)

Vaishnavi Khati [a], Ajay Kumar [a*], Amit Kishore [a], Arunima Paliwal [a], Pratiksha Raj [a], Anchal Rawat [a], Aditya Raj Bisht [a] and Pankaj Kumar [a]

[a] VCSG Uttarakhand University of Horticulture and Forestry, College of Forestry, Ranichauri (Tehri Garhwal), 249199, Uttarakhand, India.

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

Aim: Optimization of nano-DAP fertilization for improvement in growth, yield and to maximize the production of finger millet.
Study Design: Randomized Block Design (RBD).
Place and Duration of Study: This investigation was conducted in *Kharif* 2021 and 2022, with variety VL-352 at the Research and Extension Centre, Gaja, College of Forestry, Ranichauri (Tehri Garhwal), Uttarakhand, India.

**Corresponding author: E-mail: ajay25912@gmail.com;*

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Methodology: This experiment comprised of ten treatments *viz*., T1- NK 100% (Control), T2- NPK 100%, T3- 75%P + 100%N + 100%K, T4- 50%P + 100%N + 100%K, T5- 75%P + 100%N + 100%K + Seed Treatment (ST) + Foliar Spray (FS) (2mL), T6- 75%P + 100%N + 100%K + ST + FS(4mL), T7- 50%P + 100%N + 100%K + ST + FS(2mL), T8- 50%P + 100%N + 100%K + ST + FS (4mL), T9- 50%P + 100%N + 100%K + ST + FS(2mL) + FS(2mL), T10- 50%P + 100%N + 100%K + ST + FS (4mL) + FS(4mL) and was laid out in RBD with three replications. Measurements and calculations of plant growth parameters, yield attributes, and economic considerations were made.
Result: The plant growth and yield attributing parameters were recorded significantly higher in the treatment T10- 50%P +100%N + 100%K + ST + FS (4mL) + FS(4mL) while significantly lower yield was recorded in T1- NK 100% (Control).
Conclusion: The use of 50% P through DAP and 100% NK along with seed treatment by nano DAP @5mL/kg seed as well as two foliar sprays of nano-DAP @4 mL/L of water, first at 30-35 days after germination and second at 45 days after seed germination gave significantly higher plant growth, seed yield and seed quality of finger millet.

Keywords: Volatilization; denitrification; leaching losses; soil collisions; randomized block design; foliar sprays; finger millet; nano-DAP.

1. INTRODUCTION

India ranks second in the consumption and third in the production of fertilizers worldwide (Randiveet al., 2021). The usage of urea, diammonium phosphate (DAP), and muriate of potash (MOP) results in lower fertilizer efficiency due to volatilization, leaching and denitrification losses (Mohd et al., 2020), ranging from 20-50% for nitrogen, 10-25% for phosphorous and 70-80% for potassium (Chaithanya et al., 2022, Dwivedi et al., 2017). Overuse of fertilizer increases the cost of products economically that have a negative impact on farmers' income (Kumar et al., 2020). and due to its losses from the root zone, it also contributes to soil, water, and air pollution (Rahman and Zhang, 2018, Pahalvi et al., 2021), Continuous nutrient extraction from the soil along with improper and uneven fertilizer application has led to increased secondary and micronutrient deficiency due to which the ability of the crops to respond to the application of primary nutrients (N, P & K) are inhibited (Bisht and Chauhan, 2020, Prasanth and Murugan, 2021). Nitrogen and phosphorous have prominent roles in plant metabolic system, in various physiological processes, and are essential nutrients for the life of plants (Malhotra et al., 2018). The low availability of N and P limits grain yield. The management of nutrients becomes crucial for increasing the yield of the crops. Finger millet (*Eleusine coracana* (L.) Gaertn.), locally known as mandua or ragi (Rathore et al.,2019) is the most dominant *kharif* season crop in rainfed hills of Uttarakhand (Kumar et al., 2022). It is an important small millet crop grown in India that is valued for food, fodder, and high nutritional security. Even though finger millet is important, less study has been done on it and very little information is available about how to manage the crop's P levels in dry/rainfed environments. So, it is necessary to know the optimum dose of the P fertilizer to be applied for maximum yields without compromising the environment (Wafula et al.,2016).

To avoid or minimize losses from the use of chemical fertilizers, several measures have been adopted all over the world in the R & D of fertilizers. The use of nano-fertilizers acts as an alternative substitute for conventional phosphate fertilizers which are made from non-renewable phosphoric rocks whose supplies are already depleting (Tiwari et al., 2022) Nano-fertilizers through precision agriculture improves agricultural production and enhances P use efficiency (Tiwari et al., 22, Childers et al.,2011). Nanoscale materials enhances the fertilizer use efficiency while foliar application meet the crop nutrient requirement effectively as per its need. Under rainfed conditions when the availability of moisture becomes scarce, the application of nutrients as foliar spray results in efficient absorption and usage which is economical in respect to the other methods of fertilization (Kumar, 2020) Nano-P applied *via* foliar application increases P usage efficiency, promoting sustainable productivity, quality and reduces nutrient losses, P leaching/fixation into underground water through direct internalization of crops and slow release over a longer period of time while synthetic P fertilizers supplied directly to the soil have high fixation rates in the soil and low uptake efficiency (Poudel et al.,2023).

Nano-DAP formulation is an efficient source of available nitrogen (8.0% N w/v) and phosphorus (16.0 % P_2O_5 w/v) for all the crops and helps in correcting the nitrogen & phosphorus deficiencies in standing crops. Liquid nano-DAP has an advantage in terms of surface area to volume as its particle size is less than 100 nanometres (nm). The incorporation of nano-DAP into the plant system results in higher seed vigour and quality, more chlorophyll, greater photosynthetic efficiency, optimum growth and higher crop yields because the nano clusters of nitrogen.

Phosphorus in nano-DAP are functionalized with bio-polymers and other substances for enhanced spreading capacity. Additionally, nano-DAP meets the nutritional needs of crops through precise, targeted application without damaging the environment (IIFCO, 2023). As very limited information is available about the effect of nano-DAP on the finger millet growth, development, seed quality and yield, therefore, keeping this in view the present investigation has been undertaken with the objective to assess the effect of nano-DAP fertilizer on growth parameters and seed yield of finger millet.

2. MATERIALS AND METHODS

The field experiment to assess the performance of variety VL-352 of finger millet, it's growth and yield due to nano-DAP was carried out at Research and Extension Centre, Gaja, Tehri, Garhwal, Uttarakhand, India during *kharif* seasons of the years 2021 and 2022. The experiment comprised of 10 treatments as shown in Table 1 that were laid out in RBD with three replications in 30 plots each of size 2.75m x 2.5m. The recommended dose of 40: 20: 20 kg/ha NPK was used.

Plant growth parameters: Plant population per meter row length was measured by counting the number of plants present in one meter row length at 30 days after sowing (30 DAS) and at harvest stage. Other plant growth parameters such as plant height (cm), root length (cm), shoot length (cm), number of green leaves per plant and

Table 1. Treatment details and time of application

Treatment details		Abbreviations used	Time of application
T_1	0% P; Remaining N & 100% K (Control)	NK 100%	Basal application of DAP
T_2	100% P through DAP (100% N&K)	NPK 100%	Basal application of DAP
T_3	75% P through DAP (100% N&K)	75% P+ 100%N+ 100%K	Basal application of DAP
T_4	50% P through DAP (100% N&K)	50% P+ 100%N+ 100%K	Basal application of DAP
T_5	T3 + Seed treatment with nano-DAP @5ml/kg seed + Foliar spray with nano-DAP @2 mL/L of water	75%P+ 100%N+ 100%K+ ST+FS(2mL)	At 30-35 days after germination
T_6	T3 + Seed treatment with nano-DAP @5ml/kg seed + Foliar spray with nano-DAP @4 mL/L of water	75%P+ 100%N+ 100%K+ ST+FS(4mL)	At 30-35 days after germination
T_7	T4 + Seed treatment with nano-DAP @5ml/kg seed + Foliar spray with nano-DAP @2 mL/L of water	50%P+ 100%N+ 100%K+ ST+FS(2mL)	At 30-35 days after germination
T_8	T4 + Seed treatment with nano-DAP @5ml/kg seed + Foliar spray with nano-DAP @4 mL/L of water	50%P+ 100%N+ 100%K+ ST+FS(4mL)	At 30-35 days after germination
T_9	T4 + Seed treatment with nano-DAP @5ml/kg seed + 2 Foliar sprays with nano-DAP @2 mL/L of water	50%P+100%N+100%K+ST+FS (2mL) +FS(2mL)	At 30-35 & 45 days after germination
T_{10}	T4 + Seed treatment with nano-DAP @5ml/kg seed + 2 Foliar sprays with nano-DAP @4 mL/L of water	50%P+100%N+100%K+ST+FS (4mL) +FS(4mL)	At 30-35 & 45 days after germination

number of tillers per plant of five randomly selected plants from each treatment of each replication were recorded.

Yield attributes and economic parameters: Panicle length (cm), finger length (cm), and number of fingers per ear of five randomly selected plants were recorded at maturity. Test weight (g), seed yield (kg/ha), straw yield (kg/ha), biological yield (kg/ha) and harvest index % were recorded after harvesting. Economic parameters such as cost of cultivation (₹/ha), gross return (₹/ha), net return (₹/ha) and B:C ratio were also calculated.

Statistical analysis: The experimental data obtained during the investigation was statistically analysed by applying analysis of variance (ANOVA) through Randomized Block Design with OPSTAT Programme, designed and developed by O.P. Sheoran, Computer Programmer, Computer Section, CCS HAU, Hisar, India.

3. RESULTS AND DISCUSSION

Plant growth parameters: As shown by the data in Table 2, the influence of treatments on the plant population per meter row length at initial and at harvesting stage, plant height, root length, shoot length, number of green leaves per plant and number of tillers per plant were found significant. The plant population of finger millet was recorded higher at the initial stage than at the harvest stage maybe be due to mortality (intraspecific competition) of the plants (Pant and Sah, 2020) It was observed that the plant height, root length and shoot length of finger millet increased with the crop age, and this rise was rapid at the early growth stages while very slow increase from 90 DAS to the harvest stage while number of tillers per plant increased till 90 DAS and then became stagnant (Balasaheb, 2022). There was a linear increase in the number of green leaves from 30 DAS to 90 DAS maybe due to more availability of nitrogen, which might produce cytokinin and stimulate the growth of underground and aboveground parts of plants, giving them intense green colour (Harika et al.,2019, Sathishkumar et al.,2020).

The higher plant growth parameters were recorded in treatments where foliar spray of nano-DAP was applied as compared to the treatments without phosphorous application. This might be due to less fixation of the phosphorus in the soil, better absorption and utilization of macro & micro nutrients (Singhet al., 2017), more availability of nitrogen and phosphorous during the early and vegetative growth stages either through basal, seed treatment, or foliar application of nano-DAP that might have helped the plants to absorb water and light more effectively through stomata, increased chlorophyll formation, higher metabolic activity and increased photosynthesis rate resulting in taller plants, increased number of functioning leaves, higher leaf area index and possibly more number of tillers (Suriyaprabha et al., 2012, Swati et al., 2017, Patel et al.,2021).

N functions as a signalling molecule to promote seed germination by lowering the abscisic acid/gibberellins ratio (Yan et al.,2016) that regulates seed dormancy and seed germination (Nambara et al.,2010) and helps in cell division and elongation which promotes healthy vegetative growth and vigorous plant growth (Shubha et al.,2014, Ramesh et al., 2015, Yadav et al., 2017). The P present in seeds are the only P available to plants at the time of seed germination (Malhotra et al., 2018). Phosphorus is a vital component of the energy unit of plants ATP structure, which is utilized in cellular processes, including synthesis of macromolecules, membrane phospholipids and nutrient transport and processes from the beginning of seedling growth. This higher availability of phosphorus could have accelerated various physiological processes such as seed germination, seedling establishment, increased root and shoot development and higher plant growth in finger millet (Wafula et al., 2016),(Sathishkumar et al.,2020). Similar findings were also reported by (Rex Immanuel et al.,2023) that the foliar application of DAP in pigeon pea resulted in higher growth as DAP contains nutrients (nitrates and exchangeable P) which are easily available to plant shoots that are involved in cell division, cell elongation, an increase in photosynthetic activity and better accumulation of photosynthates.

Yield attributes and economic parameters: As depicted in Table 3, the yield attributes *viz*. panicle length (cm), finger length (cm), number of fingers per ear, test weight (g), seed yield (kg/ha), straw yield (kg/ha) and biological yield (kg/ha) were significantly influenced by the seed treatment and foliar application of nano-DAP. The yield attributes were recorded significantly higher in treatment T10 [50%P+ 100%N+ 100%K+ ST+FS(4mL) +FS(4mL)] which were statistically at par with T2 [100%NPK], T9 [50%P+ 100%N+100%K+ ST+FS(2mL) +FS(2mL)], T6

Table 2. Effect of nano-DAP on different plant growth parameters of finger millet

		Plant growth parameters						
S. No.	**Parameters / Treatments**	**No. of plant population/metre**		**Plant height (cm)**	**Root length (cm)**	**Shoot length (cm)**	**No. of green leaves/plant**	**No. of tillers/ plant**
		At 30DAS	**At harvest**					
T1	NK 100%	14.0	13.1	72.02	16.26	28.80	12.65	1.37
T2	NPK 100%	19.3	16.2	86.69	20.55	36.77	16.69	2.48
T3	75% P+ 100%N+ 100%K	14.8	13.5	80.56	18.90	31.08	14.83	1.61
T4	50% P+ 100%N+ 100%K	14.3	13.5	74.72	16.70	29.46	13.03	1.46
T5	75%P+ 100%N+ 100%K+ ST+FS(2mL)	15.3	15.0	81.09	18.57	30.56	14.91	1.62
T6	75%P+ 100%N+ 100%K+ ST+FS(4mL)	18.2	17.4	84.29	19.97	34.32	16.42	1.95
T7	50%P+ 100%N+ 100%K+ ST+FS(2mL)	14.7	14.0	77.02	16.95	30.47	13.66	1.51
T8	50%P+ 100%N+ 100%K+ ST+FS(4mL)	16.7	15.9	81.80	19.35	33.57	15.43	1.75
T9	50%P+100%N+100%K+ST+FS (2mL) +FS(2mL)	19.2	18.7	86.99	20.20	35.57	16.85	2.36
T10	50%P+100%N+100%K+ST+FS (4mL) +FS(4mL)	19.8	19.4	89.88	20.69	37.14	17.53	2.70
	C.D. @ 5%	**1.8**	**2.8**	**10.05**	**3.03**	**NS**	**2.03**	**0.36**
	SE(m)±	**0.6**	**0.9**	**3.36**	**1.01**	**2.19**	**0.68**	**0.12**

Table 3. Effect of nano-DAP on yield, yield attributes and economic parameters of finger millet.

Yield Attributes and Economic Parameters														
S. No.	**Parameters** **Treatments**	**Panicle length (cm)**	**Finger length (cm)**	**No. of fingers/ear**	**Panicle weight (g)**	**Test weight (g)**	**Seed yield (kg/ha)**	**Straw yield (kg/ha)**	**Biological yield (kg/ha)**	**Harvest index %**	**CoC (₹/ha)**	**Gross return (₹/ha)**	**Net return (₹/ha)**	**B:C ratio**
T1	NK 100%	6.6	5.6	6.9	5.93	2.57	1360	6751	8111	16.10	11661	47381	35720	3.06
T2	NPK 100%	7.8	6.5	8.3	8.79	2.96	1758	9546	11305	15.21	12705	60974	48269	3.80
T3	75% P+ 100%N+ 100%K	7.1	5.9	7.6	7.16	2.77	1494	8314	9808	14.63	12443	52120	39677	3.19
T4	50% P+ 100%N+ 100%K	7.0	5.6	7.1	6.10	2.63	1377	7106	8483	15.47	12182	48130	35948	2.95
T5	75%P+ 100%N+ 100%K+ ST+FS(2ml)	7.3	6.0	7.7	6.86	2.77	1501	7689	9190	15.84	12943	52114	39171	3.03
T6	75%P+ 100%N+ 100%K+ ST+FS(4ml)	7.8	6.2	8.4	7.81	2.87	1690	8836	10526	15.77	13243	58584	45341	3.42
T7	50%P+ 100%N+ 100%K+ ST+FS(2ml)	7.1	5.8	7.5	6.29	2.72	1433	7278	8711	15.72	12682	49980	37298	2.94
T8	50%P+ 100%N+ 100%K+ ST+FS(4ml)	7.3	6.0	7.7	7.29	2.82	1600	8482	10082	15.32	12982	55324	42342	3.26
T9	50%P+100%N+100%K+ ST+FS(2ml) +FS(2ml)	8.1	6.5	8.3	8.65	2.92	1770	9085	10855	15.91	13182	61168	47986	3.64
T10	50%P+100%N+100%K+ ST+FS(4ml) +FS(4ml)	8.5	6.9	8.7	9.24	3.15	1947	10035	11983	15.78	13782	67616	53834	3.91
	C.D. @ 5%	**0.7**	**0.6**	**0.7**	**1.36**	**0.20**	**228.2**	**1491.1**	**1484**	**N/A**				
	SE(m)±	**0.2**	**0.2**	**0.2**	**0.46**	**0.07**	**76.2**	**498.0**	**495**	**0.991**				

[75%P+ 100%N+ 100%K+ ST+FS(4mL)] and T8 [50%P+ 100%N+ 100%K+ ST+FS(4mL)]. The increase in the panicle length and finger length might be due to the direct availability of optimum phosphorus and nitrogen through foliar spray of nano-DAP which might have improved nutrient absorption, resulting in activated metabolic processes such as photosynthesis that helped in higher accumulation of photosynthates and translocation to the plant's economic parts, improving crop growth, development, and yield (Wafula et al.,2016, Poudel et al., 2016).The increase in the number of fingers per ear could be due to the synthesis of amino acid, chlorophyll and better transformation of carbohydrates (Shashikumar et al., 2013) The higher test weight in T10 [50%P+ 100%N+ 100%K+ ST+FS(4ml) + FS(4ml)] might be due to the positive effect of phosphorus and nitrogen to increase the leaf area index which might have increased the surface exposed to light and its absorption that may have increased the products of the carbon assimilation process in the leaf as well as stored in other plant tissues that move later when forming seeds to increase their fullness and weight gain (Sabah, 2018).

Phosphorus is a major compound in seeds and an effective source of energy as it moves into newly formed grains to gain weight. The amount of nitrogen and phosphorus applied by the foliar spray of nano-DAP enhanced all the growth parameters, dry matter production, and yield attributes as a result of greater photosynthesis that greatly influenced straw yield which affects biological yield which in turn effects grain yield production (Sharma et al., 2012, Sai Ganesh et al., 2022,) reported that the application of nano-fertilizer resulted in increased growth rate by 32.6% and seed production by 20.4% in comparison to non-nano-fertilizer. (Mer et al., 2014) also observed that foliar spray of nano-fertilizer boosted wheat crop yield and its yield attributes. The economics parameters for finger millet were calculated and presented in Table 3. The highest gross return (₹/ha), net return (₹/ha) and benefit-cost (B:C) ratio were found with the treatment T10 [50%P+ 100%N+ 100%K+ ST+FS(4mL) +FS(4mL)] while lowest were recorded in T1[0%P+NK 100%]. This might be due to the higher grain yield production. It was reported by (Pandian et al., 2001) that the application of basal dose of fertilizer along with 2% DAP spray twice gave higher net return in rice fallow green gram. (Shinde and Bhilare, 2003) also reported that the foliar spray of 2% DAP at two different growth stages registered higher gross monetary return, net monetary return and benefit-cost ratio in chickpea. Similarly, (Vinoth Kumar et al.,2013). also observed that the foliar application of 2% DAP increased the gross return, net return, and B:C ratio of soybean.

4. CONCLUSION

The present investigation clearly indicated that the use of 50% P through DAP and 100% NK along with seed treatment by nano DAP @5mL/kg seed as well as two foliar sprays of nano-DAP @4 mL/L of water, first at 30-35 days after germination and second at 45 days after seed germination gave significantly higher plant growth and seed yield of finger millet.

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 writing or editing of this manuscript.

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COMPETING INTERESTS

Author(s) have declared that no competing interests exist.

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