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Assessment of Yield and Economic Feasibility of Foliar Application of Nano Nitrogen and Nano Zinc Fertilizers on Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Crop

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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

The present experiment was carried out during *Kharif* season of 2020 at Instructional farm of College of agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan to evaluate the effect of foliar application of nano nitrogen and nano zinc on yield attributing

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parameters of pearl millet under rainfed conditions of western Rajasthan. The field experiment was laid out in randomized block design with 4 replications and 10 treatment combinations *viz.,* T_1 (Absolute control), T_2 (Recommended dose of fertilizers, RDF), T_3 (100% RDF + one spray of nano N at 25-30 DAS), T_4 (100% RDF + one spray of nano Zn at 25-30 DAS), T_5 (100% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS), T_6 (100% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS), T_7 (75% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS), T_8 (75% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS), T_9 (50% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS), T_{10} (50% RDF + two spray of nano Zn at 25-30 DAS and 45- DAS). Growth, yield, and economic parameters were statistically analysed using Analysis of Variance as per Fisher's method. Results revealed, that the application of nano-fertilizers significantly enhanced the growth attributes, yield of pearl millet compared with the conventional fertilization practices. Among the evaluated treatments, T_5 (100% RDF + two foliar sprays of nano-N at 25–30 Days after Sowing and 45–50 Days after Sowing) recorded the highest grain yield and net returns, indicating its superiority in terms of productivity and economic viability.

Keywords: Pearl millet; nano nitrogen; nano zinc; foliar fertilization; yield attributes; semi-arid region.

1. Introduction

"Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a major coarse cereal crop predominantly grown under rainfed conditions in arid and semi-arid regions" (T.R. et al., 2024). It ranks fifth among global cereal crops after rice, wheat, maize, and sorghum. Owing to its high tolerance to drought, heat, and low soil fertility, pearl millet plays a vital role in food and nutritional security in climatically vulnerable areas. The crop contributes nearly 50% of global millet production. "India is the world's largest producer of pearl millet in terms of both area and production. During 2017–18, pearl millet occupied about 7.4 million hectares in India, producing 9.13 million tonnes with an average productivity of 1237 kg ha^{-1}" (Anonymous, 2018). It is nutritionally superior to many major cereals containing approximately 67.5% carbohydrates, 11.6% protein, 5.0% fat, and 2.3% minerals. Despite its wide adaptability and nutritional importance, pearl millet productivity in western Rajasthan remains low due to poor soil fertility, low organic carbon, and inefficient nutrient management. The predominantly sandy soils of the region are deficient in essential nutrients, particularly nitrogen (N) and zinc (Zn). Nitrogen, a key component of chlorophyll and proteins, is crucial for photosynthesis, vegetative growth, and yield formation. Zinc plays an essential role in enzymatic activity, auxin synthesis, and photosynthate translocation. Deficiencies of N and Zn adversely affect growth, yield attributes, and nutrient balance in pearl millet. Conventional fertilizer application in light-textured soils results in substantial nutrient losses and fertilizer low use efficiency (DeRosa *et al.*, 2010). In rainfed systems, erratic rainfall and soil moisture stress further constrains nutrient availability. Foliar nutrient application serves as an effective supplement to soil fertilization by enabling rapid nutrient uptake, reducing losses, and improving nutrient use efficiency, particularly at critical crop growth stages (Rameshaiah *et al.*, 2015; Manikandan and Shirmohammadi, 2015; Morales-Díaz *et al.*, 2017; Singh, 2017; Karthik et al., 2024).

Recent advancements in nanotechnology have led to the development of nano fertilizers, which provide an efficient nutrient delivery system due to their nano-scale size, higher surface area, and controlled nutrient release behaviour. Nano nitrogen and nano zinc fertilizers enhance nutrient absorption, translocation, and utilization efficiency while significantly reducing fertilizer requirement and environmental contamination. Several studies have reported that nano fertilizers improve crop growth, yield attributes, nutrient uptake, and stress tolerance compared to conventional fertilizers. Recent advances in nanotechnology have led to the development of nano-fertilizers that enable efficient nutrient delivery due to their nano-scale size, high surface area, and controlled release properties. Nano nitrogen and nano zinc fertilizers enhance nutrient uptake, translocation, and use efficiency while reducing fertilizer requirements and environmental contamination. Studies have reported improved crop growth, yield attributes, nutrient uptake, and stress tolerance with nano-fertilizers over conventional fertilizers. Therefore, the present study was conducted to evaluate the effect of foliar application of nano nitrogen and nano zinc on yield attributing parameters of pearl millet under rainfed conditions of western Rajasthan.

2. Materials and Methods

The present experiment was carried out during *Kharif* season of 2020 at Instructional farm of College of agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan which is situated at 28º10' N latitude, 73º18' E longitude and 223.88 meters above mean sea level. RHB-177 variety of pearl millet was sown at the rate of 4 kg seed per hectare having 45 cm row to row and 15 cm plant to plant spacing. The plot size was 5 m x 4.5 m. Seeds of pearl millet variety RHB-177 were treated with *Trichoderma harzianum* @ 4g kg^{-1} as prophylactic measures against soil borne diseases. The crop was sown in rows and plant spaced respectively, at 45 x 15 cm distance. Seed rate of pearl millet was 4 kg ha^{-1}. All the remaining standard agronomic package of practices were followed to raise the good crop. The field experiment was laid out in randomized block design with 4 replications and 10 treatment combinations as mentioned in Table 1.

Treatment application was done in two forms. In nano fertilizer, Foliar Spray of N (4 per cent) and Zn (1 per cent) nano fertilizer was done at 25-30 DAS and 45-50 DAS according to different combinations of treatments. Fertilizers application was done with side drilling method of fertilizer application according to recommended dose of fertilizer (60 kg ha^{-1} N and 40 kg ha^{-1} P_2O_5) for pearl millet crop. Each plot was harvested separately, tied in bundles and tagged. For the observations related to yield attributing parameters; five plants were selected randomly from each replicated plot and were tagged. Observations like plant height (cm), numbers of effective tillers (per square meter), effective number of tillers per meter row length, number of grains per ear head, test weight (g), length (cm), weight (g) of ear head, grain yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index (%) were measured. For the evaluation of the economic feasibility of the treatment combinations, cost of cultivation (₹ ha^{-1}), gross returns (₹ ha^{-1}), net returns (₹ ha^{-1}), Benefit: Cost ratio was also worked out. Experimental data recorded in various observations were statistically analysed to test the significance of variance in experiments, as per procedure described by Fisher's analysis of variance technique.

3. Results and Discussion

The results presented in Table 2 clearly demonstrated that foliar application of nitrogen (N) and zinc (Zn) nano-fertilizers exerted a significant influence on yield attributes and yield of pearl millet. Plant height increased progressively with crop growth stages and attained maximum at harvest. Among the treatments, T5 (100% RDF + two foliar sprays of nano N at 25–30 and 45–50 DAS) recorded the tallest plants (178 cm), which was statistically at par with T6 (173 cm). A similar trend was observed for effective tillers per meter row length, where treatment T5 produced the maximum number of effective tillers (18.25 m^{-1}), followed by T6 (17.25 m^{-1}). The enhanced vegetative growth under nano-fertilizer application indicates improved nutrient availability and utilization efficiency.

Yield attributes were also significantly influenced by foliar application of nano N and Zn fertilizers. Treatment T5 recorded the highest number of grains per ear head (3310), test weight (7.40 g), ear head length (26.0 cm) and ear head weight (32.39 g), which remained statistically comparable with treatment T6. In contrast, the lowest values of these parameters were observed under the absolute control (T1). The improvement in yield attributes under nano-fertilizer treatments may be attributed to enhanced photosynthetic efficiency, better assimilate production and effective translocation of photosynthates towards reproductive parts, resulting in improved sink strength.

Table 1. Details of treatments with their symbols

Treatments	Treatments details
T_1	Absolute control
T_2	Recommended dose of fertilizers [RDF]
T_3	100% RDF + one spray of nano N at 25-30 DAS
T_4	100% RDF + one spray of nano Zn at 25-30 DAS
T_5	100% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS
T_6	100% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS
T_7	75% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS
T_8	75% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS
T_9	50% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS
T_{10}	50% RDF + two spray of nano Zn at 25-30 DAS and 45- DAS

Table 2. Effect of foliar application of N and Zn nano fertilizers on yield attributing and yield parameters of pearl millet

Treatments	Plant height (cm)	Number of effective tillers m^{-1} row length	Number of grains per ear head	Test weight (g)	Ear head length (cm)	Ear head Weight (g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1- (Absolute control)	135.00	10.50	2009	6.30	16.00	17.65	1266	3588	26.08
T_2- (Recommended dose of fertilizer) (60:40)	160.00	15.50	2832	7.00	22.00	26.80	1983	4390	31.05
T_3- (100% RDF +one spray of nano N at 25-30 DAS)	171.00	17.00	3103	7.25	24.25	30.00	2251	4900	31.58
T_4- (100% RDF + one spray of nano Zn at 25-30 DAS)	168.00	16.50	3037	7.20	23.50	29.16	2187	4775	31.38
T_5- (100% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS)	178.00	18.25	3310	7.40	26.00	32.39	2450	5309	31.56
T_6- (100% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS)	173.00	17.25	3116	7.30	24.50	30.44	2275	5130	30.71
T_7- (75% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS)	158.00	15.25	2826	6.90	21.00	26.40	1950	4373	30.82
T_8- (75% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS)	154.00	14.00	2779	6.80	20.00	25.59	1890	4200	30.99
T_9- (50% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS)	151.00	13.75	2513	6.70	19.75	23.45	1688	3918	30.13
T_{10}- (50% RDF + two spray of nano Zn at 25-30 DAS and 45-50 DAS)	146.00	12.00	2475	6.60	19.00	22.53	1634	3666	30.85
S.Em±	**1.83**	**0.41**	**69.25**	**0.04**	**0.56**	**0.63**	**63.73**	**69.85**	**0.73**
CD (p = 0.05)	**5.30**	**1.20**	**200.95**	**0.12**	**1.61**	**1.81**	**188.93**	**202.69**	**2.12**

Table 3. Effect of foliar application of N and Zn Nano fertilizers on economic feasibility of pearl millet

Treatments	**Total cost of cultivation (₹ ha^{-1})**	**Gross returns (₹ ha^{-1})**	**Net returns (₹ ha^{-1})**	**B:C ratio**
T1- Absolute control	18005.00	41994.00	23989.00	2.33
T2- Recommended dose of fertilizers [RDF] (60:40)	20512.00	59627.00	39115.00	2.90
T3- 100% RDF +one spray of nano N at 25-30 DAS	21130.00	67269.00	46139.00	3.18
T4- 100% RDF +one spray of nano Zn at 25-30 DAS	21870.00	65428.00	43558.00	2.99
T5- 100% RDF +two spray of nano N at 25-30 DAS and 45-50 DAS	21748.00	73095.00	51347.00	3.36
T6- 100% RDF +two spray of nano Zn at 25-30 DAS and 45-50 DAS	23228.00	68875.00	45647.00	2.96
T7- 75% RDF +two spray of nano N at 25-30 DAS and 45-50 DAS	21127.00	58915.00	37788.00	2.78
T8- 75% RDF +two spray of nano Zn at 25-30 DAS and 45-50 DAS	22607.00	56910.00	34303.00	2.51
T9- 50% RDF +two spray of nano N at 25-30 DAS and 45-50 DAS	20494.00	51662.00	31168.00	2.52
T10- 50% RDF +two spray of nano Zn at 25-30 DAS and 45-50 DAS	21974.00	49376.00	27402.00	2.24
S.Em±	-	-	1304.61	-
CD (p = 0.05)	-	-	3785.61	-

The enhanced growth observed under nano N and Zn application may be due to improved synthesis of growth-promoting hormones such as auxins, leading to increased cell division and elongation. Zinc plays a vital role in auxin metabolism, while nitrogen is essential for chlorophyll formation, protein synthesis and overall vegetative growth. These physiological effects collectively resulted in better crop growth, as also reported by Chavan et al. (2019), Benzon *et al*. (2015), Nalwade and Neharkar (2013).

Grain and stover yields of pearl millet were significantly affected by the treatments. The highest grain yield (2450 kg ha^{-1}) and stover yield (5309 kg ha^{-1}) were obtained under treatment T5, representing an increase of 93.52% and 47.96%, respectively, over the absolute control, and 23.55% and 20.93% over RDF alone. Treatment T6 ranked next, whereas the lowest grain and stover yields were recorded under T1. Although harvest index was highest under T3 (31.58%), the superior biomass production and grain yield under T5 clearly indicated the advantage of two foliar sprays of nano N in combination with RDF. The higher yield and yield attributes under nano-fertilizer treatments can further be explained by improved nutrient

Treatment cost: Urea- ₹ 5.36 kg $^{-1}$; SSP- ₹ 7.24 kg $^{-1}$; 1 bottle (500 ml) of nano N = ₹ 618 ha^{-1}; 1 bottle (500 ml) of nano Zn = ₹ 1358 ha^{-1}.

Selling rate: Grain = 1900 ₹ q^{-1}; Stover = 500 ₹ q^{-1}; absorption efficiency and enhanced metabolic activities such as photosynthesis, leading to greater accumulation and translocation of photosynthates to economic parts of the plant. This increased source–sink relationship ultimately resulted in higher grain and biomass yield, in agreement with the physiological concepts described in previous study. Similar beneficial effects of nano-fertilizers on crop productivity have also been reported by Abdel-Aziz *et al*. (2016), Hafeez *et al.* (2015), Harsini *et al*. (2014), Kumar *et al*. (2014), Sirisena *et al*. (2013) and Sheikhbaglou *et al*. (2010).

Data presented in Table 3 indicated that foliar application of N and Zn nano fertilizers significantly affected the Net returns and B: C ratio. From the data, it was observed that highest B: C ratio (3.36) and net returns (₹ 51347.00) was observed in treatment T_5 (*i.e.* 100% RDF + two spray of nano N at 25-30 DAS and 45-50 DAS), followed by T_3 (100 % RDF + one spray of nano N at 25-30 DAS) and lowest B: C ratio (2.24) was noted under treatment T_{10} (*i.e.* 50% RDF + two spray of nano Zn at 25- 30 DAS and 45-50 DAS) and lowest net returns (₹ 23989.00) was recorded in treatment no T_1 (absolute control). The results showed that foliar application of N and Zn nano fertilizers with RDF increase the B: C ratio so it is indicated that the proper use of nano fertilizers with RDF is economically good. It may be due to less return and higher cost of nano Zn fertilizer. Similar result is reported by Swati and Bharat (2017) and Kumar *et al.,* (2014). Overall study conclusively indicated that foliar application of nano nitrogen, particularly two sprays in combination with recommended dose of fertilizers, is an effective nutrient management strategy for enhancing growth, yield attributes and productivity of pearl millet.

4. Conclusion

On the basis of experiment results of the present investigation, it may be concluded that the application of nano-fertilizers significantly enhanced the growth attributes, yield of pearl millet compared with the conventional fertilization practices. Among the evaluated treatments, T_5 (100% RDF + two foliar sprays of nano-N at 25–30 DAS and 45–50 DAS) recorded the highest grain yield and net returns, indicating its superiority in terms of productivity and economic viability. However, these results are only indicative and require further experimental conformation before making the final recommendation to farmers.

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 they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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