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## Effect of precision zinc management on growth, yield attributes and yield of pearl millet (*Pennisetum glaucum* L.)

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#### ABSTRACT

The present investigation, entitled Effect of Precision Zinc Management on Growth, Yield Attributes and Yield of Pearl Millet (*Pennisetum glaucum* L.), was conducted during the kharif season of 2025 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh. The experiment was laid out in a Randomized Complete Block Design with eight treatments replicated thrice, viz., T<sub>1</sub> - Control (No Zn), T<sub>2</sub> - Soil application of Zn @ 5 kg ha<sup>-1</sup> at sowing, T<sub>3</sub> - Foliar spray of Zn @ 0.1% at tillering and pre-flowering, T<sub>4</sub> - Foliar spray of Nano zinc (IFFCO) @ 0.04% at tillering and pre-flowering, T<sub>5</sub> - Foliar spray of Nano zinc particles @ 100 ppm at tillering and pre-flowering, T<sub>6</sub> - Soil Zn @ 2.5 kg ha<sup>-1</sup> + foliar Zn @ 0.1%, T<sub>7</sub> - Soil Zn @ 2.5 kg ha<sup>-1</sup> + Nano zinc (IFFCO) @ 0.04%, and T<sub>8</sub> - Soil Zn @ 5 kg ha<sup>-1</sup> + Nano zinc particles @ 100 ppm. The results revealed that precision zinc management significantly influenced dry matter accumulation, leaf area index at harvest, yield attributes, grain yield, harvest index of pearl millet, while plant height, earhead length, earhead girth, stover yield, biological yield, gross returns and net returns were not significantly influenced. The treatment T<sub>7</sub> (Soil Zn @ 2.5 kg ha<sup>-1</sup> + Nano zinc (IFFCO) @ 0.04%) recorded the highest plant height (201 cm) and dry matter accumulation (645 g m<sup>-2</sup>) at harvest, the maximum number of earheads m<sup>-2</sup> (32.4), grains earhead<sup>-1</sup> (942), test weight (8.97 g) and grain yield (2.21 t ha<sup>-1</sup>), representing an increase of 20.8% in grain yield over the control (T<sub>1</sub>) and 11.6% over T<sub>2</sub>. The minimum values for growth parameters and yield attributes, yield were, in general, recorded under the control (T<sub>1</sub>).

**Keywords:** Growth parameters, Nano zinc, Pearl millet, Precision zinc management, Yield attributes

#### Introduction

Pearl millet (*Pennisetum glaucum* L.) is a drought-tolerant, warm-season cereal grown for both grain and fodder, and ranks sixth among the world's cereals after rice, wheat, maize, barley and sorghum. It can be cultivated on soils with poor organic matter and low water-holding capacity, and is well adapted to marginal, saline and acidic lands where minimal annual rainfall of 300-500 mm makes it the crop of choice for rainfed dryland ecologies (Faiz *et al.*, 2022). India is the largest producer of pearl millet in the world, with a cultivated area of about 7.0 million hectares, production of 9.5 million tonnes and productivity of 1360 kg ha<sup>-1</sup>, in Uttar Pradesh, the crop occupies about 1.01 million hectares with a productivity of 2173 kg ha<sup>-1</sup> (Mohammed *et al.*, 2024) [1], indicating considerable scope for improving productivity through better agronomic management. Zinc is the fourth most yield-limiting nutrient in crop production after nitrogen, phosphorus and potassium (Khinchu *et al.*, 2017) [2], and more than 50 per cent of Indian soils are reported to be deficient in available zinc (Kumar *et al.*, 2016) [3]. Zinc is a structural and catalytic component of numerous enzymes and proteins associated with carbohydrate metabolism, auxin (IAA) biosynthesis, protein synthesis and maintenance of membrane integrity (Alloway, 2008) [4]. Its deficiency retards photosynthesis, delays flowering and fruiting, prolongs the growth period and reduces both yield and the efficiency with which applied nutrients are converted into economic produce. Since zinc directly governs cell division, cell elongation and chlorophyll synthesis, an adequate and timely supply of this micronutrient is essential for realising the full growth and yield potential of pearl millet, and consequently the profitability of its cultivation. Soil-applied zinc sulphate, although the most common source of zinc, is highly prone to fixation as insoluble carbonates, phosphates and hydroxides in near-neutral to alkaline soils, which restricts its availability to the crop and necessitates the application of comparatively large and costlier doses. Foliar application overcomes this constraint, as the nutrient is absorbed directly through the leaf surface and becomes rapidly available to the metabolically active tissues, while nano-zinc formulations, owing to their small particle size and large surface area, are reported to further improve leaf penetration and uptake efficiency at much lower rates of application than conventional zinc sulphate. A combination of a basal soil application with a need-based foliar spray of conventional or nano zinc may

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therefore be expected to sustain zinc availability throughout the crop growth period, from the vegetative stage through panicle initiation and grain filling, and to translate more efficiently into improved growth and yield than either method applied alone. However, information comparing the relative efficiency of such soil, foliar and nano-zinc sources, applied singly and in combination, on the growth, yield formation and economic feasibility of pearl millet under the alluvial soils of western Uttar Pradesh is limited.

Keeping these considerations in view, the present investigation entitled Effect of Precision Zinc Management on Growth, Yield Attributes and Yield of Pearl Millet (*Pennisetum glaucum* L.), was undertaken at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (U.P.), during the *kharif* season of 2025, with the specific objective of studying the effect of precision zinc management on the growth, yield attributes, yield and economics of pearl millet.

## Materials and Methods

The field experiment was conducted during the *kharif* season of 2025 at the Crop Research Centre (Main Campus), Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (U.P.), situated at 29° 08' N latitude and 77° 42' E longitude at an altitude of 237 m above mean sea level, in a semi-arid sub-tropical climate. The soil of the experimental field was Gangetic alluvial (Ustochrept) of sandy loam texture, with a pH of 7.71, electrical conductivity of 0.17 dS m<sup>-1</sup>, organic carbon 0.30%, and medium available nitrogen (190.6 kg ha<sup>-1</sup>), phosphorus (14.3 kg ha<sup>-1</sup>), potassium (230.4 kg ha<sup>-1</sup>) and zinc (0.56 mg kg<sup>-1</sup>). The experiment was laid out in a Randomized Complete Block Design with eight treatments replicated thrice (24 plots), with a gross plot size of 5.1 m × 4.5 m and a net plot size of 3.3 m × 3.3 m. The pearl millet hybrid TMBH-633 was sown on 28 July 2025 at a seed rate of 5 kg ha<sup>-1</sup> and a spacing of 45 cm × 15 cm. A uniform recommended dose of fertilizer (60:40:40 kg NPK ha<sup>-1</sup>) was applied to all the treatments, with half the nitrogen and the full dose of phosphorus and potassium applied as basal dressing and the remaining nitrogen top-dressed subsequently, so that treatment differences could be attributed solely to the superimposed zinc management practices. The eight treatments comprised:

T<sub>1</sub> - Control (No Zn)

T<sub>2</sub> - Soil application of Zn @ 5 kg ha<sup>-1</sup> at sowing

T<sub>3</sub> - Foliar spray of Zn @ 0.1% at tillering and pre-flowering

T<sub>4</sub> - Foliar spray of Nano zinc (IFFCO) @ 0.04% at tillering and pre-flowering

T<sub>5</sub> - Foliar spray of Nano zinc particles @ 100 ppm at tillering and pre-flowering

T<sub>6</sub> - Soil Zn @ 2.5 kg ha<sup>-1</sup> + foliar Zn @ 0.1%

T<sub>7</sub> - Soil Zn @ 2.5 kg ha<sup>-1</sup> + Nano zinc (IFFCO) @ 0.04%

T<sub>8</sub> - Soil Zn @ 5 kg ha<sup>-1</sup> + Nano zinc particles @ 100 ppm

Growth parameters, viz., plant height (cm), dry matter accumulation (g m<sup>-2</sup>) and leaf area index,

were recorded from five randomly tagged plants (or a one square-metre sampling area, as applicable) at the tillering, pre-flowering and harvest stages. Yield attributes, viz., number of earheads m<sup>-2</sup>, earhead length (cm), earhead girth (cm), number of grains earhead<sup>-1</sup> and test weight (g), were recorded at harvest. Grain, stover and biological yields (t ha<sup>-1</sup>) were recorded plot-wise on a dry-weight basis, and harvest index (%) was calculated as the ratio of grain yield to biological yield following Donald (1962) [5]. The data recorded for all the parameters were statistically analysed by analysis of variance (ANOVA) as outlined by Gomez *et al.* (1984) [6] using SPSS software, and critical difference (CD) values were worked out at the 5 per cent level of probability wherever the *F*-test was significant.

## Results and discussion

### Growth parameters plant height (cm)

The data on plant height as influenced by precision zinc management are presented in Table 1. The differences among the treatments were found to be statistically non-significant at the harvesting stage.

Numerically, however, the maximum plant height (201 cm) was recorded under T<sub>7</sub> (Soil Zn @ 2.5 kg ha<sup>-1</sup> + Nano zinc (IFFCO) @ 0.04%), followed by T<sub>8</sub> (196 cm) and T<sub>6</sub> (193 cm), whereas the minimum plant height (180 cm) was recorded under the control (T<sub>1</sub>). The plant height under T<sub>7</sub> was 8.1% higher than T<sub>2</sub> (Soil application of Zn @ 5 kg ha<sup>-1</sup> at sowing) and 11.7% higher than the control (T<sub>1</sub>).

Zinc is an essential co-factor for the biosynthesis of tryptophan, a precursor of the growth hormone indole acetic acid (IAA), and is also involved in chlorophyll synthesis; adequate zinc nutrition therefore promotes cell division and cell elongation, which is reflected in improved plant height. The comparatively taller plants recorded under the combined soil plus foliar treatments (T<sub>7</sub> and T<sub>8</sub>) may be ascribed to the sustained availability of zinc from the basal soil dose together with the rapid absorption of the foliar-applied fraction. Similar improvement in plant height of pearl millet with zinc application has been reported by Prasad *et al.* (2014) [7] and Shekhawat *et al.* (2017) [8], who recorded taller plants with soil and foliar application of ZnSO<sub>4</sub> as compared to the unfertilized control.

### Dry matter accumulation (g m<sup>-2</sup>)

The data presented in Table 1 revealed that dry matter accumulation was statistically non-significantly influenced by precision zinc management at the harvest stage. Numerically, the maximum dry matter accumulation (645 g m<sup>-2</sup>) was recorded under T<sub>7</sub> (Soil Zn @ 2.5 kg ha<sup>-1</sup> + Nano zinc (IFFCO) @ 0.04%), followed by T<sub>8</sub> (632 g m<sup>-2</sup>) and T<sub>6</sub> (624 g m<sup>-2</sup>), whereas the minimum dry matter accumulation (568 g m<sup>-2</sup>) was recorded under the control (T<sub>1</sub>). The dry matter accumulation under T<sub>7</sub> was 6.6% higher than T<sub>2</sub> (605 g m<sup>-2</sup>) and 13.6% higher than the control.

The higher dry matter accumulation under the combined zinc treatments may be attributed to the greater photosynthetic efficiency resulting from improved chlorophyll synthesis and hormonal activity under adequate zinc nutrition, which in turn enhanced vegetative growth and biomass build-up. The comparatively higher dry matter accumulation under the combined soil and foliar route suggests that the two modes of application acted complementarily, with the soil-applied fraction providing a sustained basal supply and the foliar spray meeting the crop demand during the critical growth stages. These findings are in agreement with Arshewar *et al.* (2018) [9], who recorded higher dry matter accumulation with zinc application, and Chandra (2021) [10], who reported that combined application of nitrogen and zinc increased the dry matter and crop growth rate of pearl millet.

### Leaf area index

The leaf area index (Table 1) did not vary significantly among the treatments at the harvest

stage. Numerically, the maximum leaf area index (5.84) was recorded under T<sub>7</sub> (Soil Zn @ 2.5 kg ha<sup>-1</sup> + Nano zinc (IFFCO) @ 0.04%), followed by T<sub>8</sub> (5.25) and T<sub>6</sub> (4.93), whereas the minimum leaf area index (3.88) was recorded under the control (T<sub>1</sub>). The leaf area index under T<sub>7</sub> was 30.4% higher than T<sub>2</sub> (4.48) and 50.5% higher than the control.

The higher leaf area index recorded under the zinc-treated plots, particularly under the combined soil and foliar treatment, may be explained by the role of zinc in chlorophyll synthesis and vegetative development, which favoured greater leaf initiation and expansion during the crop growth period. The comparatively higher leaf area index under T<sub>7</sub> may also be associated with the combined availability of zinc through soil application and foliar supplementation. A similar improvement in the leaf area index of pearl millet with foliar zinc application has been reported by Maharana *et al.* (2021) [11].

**Table 1.** Effect of precision zinc management on growth parameter of pearl millet at harvest

(continued on next page)

### Yield attributes and yield earheads $m^{-2}$

The number of earheads  $m^{-2}$  (Table 2) was significantly influenced by precision zinc management. The maximum number of earheads ( $32.4 m^{-2}$ ) was recorded under  $T_7$ , which remained statistically *at par* with  $T_6$  ( $30.2 m^{-2}$ ) and  $T_8$  ( $31.0 m^{-2}$ ), but was significantly superior to the remaining treatments. The minimum number of earheads was recorded under the control ( $T_1$ ). Zinc is known to influence tiller and panicle initiation through its effect on auxin metabolism, and the higher earhead

number recorded under the combined zinc treatments is consistent with the findings of Choudhary *et al.* (2017) [12] and Sandeep *et al.* (2024) [13], who reported a significant improvement in the number of ears/earheads of pearl millet with zinc application.

### Earhead length and earhead girth (cm)

The differences among the treatments were non-significant for both earhead length and earhead girth. However, the maximum earhead length (22.4 cm) and earhead girth (9.17 cm) were recorded under  $T_7$ , followed by  $T_8$ ,  $T_6$  and  $T_4$ , while the minimum values for both traits were recorded under the control. A similar improvement in earhead length with zinc biofortification has been reported by Arshewar *et al.* (2018) [9] and Reddy *et al.* (2022) [14].

### Grains earhead $^{-1}$

The number of grains earhead $^{-1}$  was significantly influenced by the treatments. The maximum number of grains earhead $^{-1}$  (942) was recorded under  $T_7$ , which remained statistically *at par* with  $T_6$  (879) and  $T_8$  (912), but was significantly higher than the remaining treatments; the minimum was recorded under the control. Adequate zinc supply during the tillering and pre-flowering stages, coinciding with panicle initiation and grain-filling phases in the present study, is likely to have improved spikelet fertility and pollen viability, resulting in a greater number of grains per earhead, a trend also reported by Girish *et al.* (2023) [15].

### Test weight (g)

Test weight was significantly influenced by precision zinc management, the maximum (8.97 g) being recorded under  $T_7$ , which remained statistically *at par* with  $T_6$  (8.57 g),  $T_8$  (8.77 g),  $T_5$  (8.21 g) and  $T_4$  (8.31 g), but significantly higher than the remaining treatments. The minimum test weight was recorded under the control.

**Table 2.** Effect of precision zinc management on yield attributes of pearl millet

### Yield $t ha^{-1}$ (grain, stover and biological) and harvest index (%) of pearl millet

#### Grain yield ( $t ha^{-1}$ )

Grain yield (Table 5) was significantly influenced by precision zinc management. The maximum grain yield ( $2.21 t ha^{-1}$ ) was recorded under  $T_7$ , which remained statistically *at par* with  $T_4$  ( $2.08 t ha^{-1}$ ),  $T_5$  ( $2.01 t ha^{-1}$ ),  $T_6$  ( $2.11 t ha^{-1}$ ) and  $T_8$  ( $2.19 t ha^{-1}$ ), but was significantly higher than the remaining treatments;  $T_7$  out-yielded the control and  $T_2$  by 20.8% and 11.6%, respectively. The minimum grain yield was recorded under the control.

Since grain yield is essentially the cumulative product of the number of earheads per unit area, the number of grains per earhead and the test weight, the higher grain yield recorded under the combined zinc treatments is a direct consequence of the improvement observed in each of these component yield attributes. The synergistic response obtained when zinc was applied through combined soil and foliar routes ( $T_7$  and  $T_8$ ), as compared to either method applied alone, suggests that the split-application approach was able to meet the crop's zinc requirement continuously through the growing season, with the soil-applied fraction providing a sustained basal supply and the foliar sprays meeting the peak demand at the critical reproductive stages. Similar

improvement in grain yield of pearl millet with combined or foliar zinc application has been reported by Reddy *et al.* (2022) [14] and Girish *et al.* (2023) [15], while the synergism between soil and foliar zinc application has also been highlighted by Choudhary *et al.* (2017) [12] and Kumar *et al.* (2021).

### Stover yield and biological yield ( $t ha^{-1}$ )

The differences among the treatments were found to be non-significant for both stover yield and biological yield. The maximum stover yield ( $4.67 t ha^{-1}$ ) was recorded under  $T_3$ , followed by  $T_7/T_1$ ,  $T_4$  and  $T_2$ , while the minimum was recorded under  $T_5$ . The maximum biological yield ( $6.62 t ha^{-1}$ ) was recorded under  $T_7$ , followed by  $T_3$  ( $6.61 t ha^{-1}$ ),  $T_8$  ( $6.59 t ha^{-1}$ ) and  $T_6$  ( $6.44 t ha^{-1}$ ); the foliar application of nano-zinc particles under  $T_4$  and  $T_5$  increased biological yield by 3.3% and 1.4%, respectively, over the control, while the minimum biological yield was recorded under the control.

### Harvest index (%)

Harvest index was significantly influenced by precision zinc management, with the maximum value (33.4%) recorded under  $T_7$ , which was statistically *at par* with  $T_8$  (33.2%) but significantly higher than the remaining treatments; the minimum harvest index (29.3%) was recorded under the control. The higher harvest index recorded under  $T_7$  indicates a more efficient partitioning of photosynthates towards the economic (grain) sink, which is consistent with the reports of Panda *et al.* (2020) [16] and Kavya *et al.* (2023) [17], who recorded an improvement in the harvest index of pearl millet with zinc fertilization.

**Table 3.** Effect of precision zinc management on yield (grain, stover and biological) and harvest index of pearl millet

### Conclusion

Based on the results of the present one-year field investigation, it can be concluded that precision zinc management significantly influenced the growth, yield attributes, yield and economics of pearl millet under the semi-arid alluvial soils of western Uttar Pradesh. The combined application of soil zinc @  $2.5 kg ha^{-1}$  at sowing with a foliar spray of nano zinc (IFFCO) @ 0.04% at the tillering and pre-flowering stages ( $T_7$ ) proved most effective, recording the highest plant height and dry matter accumulation at harvest, the maximum yield attributes, the highest grain yield ( $2.21 t ha^{-1}$ , a 20.8% increase over the control). Thus, a split application of zinc through the soil at sowing combined with a foliar spray of conventional or nano zinc at the tillering and pre-flowering stages may be recommended for realising higher growth, productivity and profitability of pearl millet under similar agro-climatic conditions, although further validation over more seasons and locations is warranted before a firm recommendation can be made.

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