



RESEARCH ARTICLE

Response of fodder barley to the application of nano-urea in conjunction with zinc fertilization in Trans-Gangetic Plains of India

Anushka Mishra¹, Pranav Patil¹, Rajeev Kumar Gupta^{2,3*}, Princy Thakur¹, Zeeshan Tanvir Ahmed², Meraj Ahmed¹, Sreethu² & R Singh⁴

¹Department of Soil Science and Agricultural Chemistry, Lovely Professional University, Phagwara 144 411, Punjab, India

²Department of Agronomy, Lovely Professional University, Phagwara 144 411, Punjab, India

³Department of Soil Science, Punjab Agricultural University, Ludhiana 141 004, Punjab, India

⁴Department of Horticulture, Lovely Professional University, Phagwara 144 411, Punjab, India

*Correspondence email - rajeev.30662@lpu.co.in

Received: 25 May 2025; Accepted: 30 September 2025; Available online: Version 1.0: 26 January 2026

Cite this article: Anushka M, Pranav P, Rajeev KG, Princy T, Zeeshan T A, Meraj A, Sreethu, Singh R. Response of fodder barley to the application of nano-urea in conjunction with zinc fertilization in Trans-Gangetic Plains of India. *Plant Science Today*. 2026;13(sp1):01-06. <https://doi.org/10.14719/pst.9608>

Abstract

In contemporary agriculture, nano-fertilizers have great promise for improving nutrient use efficiency and minimizing nutrient loss to the environment. However, little is known about the effectiveness of zinc (Zn) and nano-urea fertilization on different barley varieties. The objective of the study was to evaluate the effect of different application rates of the recommended dose of fertiliser (50, 75 and 100 %) along with nano-urea sprays and zinc fertilization in evaluating growth and yield performance of two varieties of barley (PL 172 and PL 426). The study also focused on how different treatments affected the soil characteristics. The experiment was carried out in a split-plot design and was replicated thrice. The results confirmed that green and dry fodder yields, quality attributes and final soil nutrient status were significantly influenced by different treatments under consideration. The results showed that maximum green fodder yield ($t\ ha^{-1}$), dry fodder yield ($t\ ha^{-1}$), crude protein (%), ash content (%), crude fiber (%) and total carbohydrate content (%) were obtained with PL 172 variety and with the application of 75 % Recommended Dose of Nitrogen (RDN) + two nano-urea sprays + two foliar zinc sprays.

Keywords: barley; nano-urea; yield; zinc

Introduction

In majority of farming systems, livestock are integral to supporting and enhancing agricultural productivity. However, the growing human and animal populations are competing for limited land resources for food and fodder. Only 4 % of the nation's total arable land is used for fodder production (1,2). Fodder production in India is highly unequally distributed. How this resource is exploited varies depending on the climate, socioeconomic situation, crop-growing patterns and the breed of cattle reared. Regarding milk output, India leads the world (3,4). Therefore, the success of the nation's cattle business depends heavily on the supply of high-quality fodder and forage. When feeding high-yielding milch animals, green fodder is crucial for achieving the best possible degree of milk output. One of the biggest obstacles to livestock production is a lack of fodder. The most beneficial and economical feed source for livestock is green fodder, which offers a wealth of vital minerals, water, proteins, carbs and energy. Only 45–50 % of the country's current fodder resources can match the demand and the extent of the fodder shortage varies by state. The nation currently has a net deficiency of 44 % concentrate feed ingredients, 10.95 % dry crop leftovers and 35.6 % green fodder (5). Higher-quality fodder is crucial for milk production, delivering more Crude Protein (CP) and other nutrients to the small

intestine. Inadequate access to nutrient-rich feeds and fodder leads to sick animals and lower dairy production (2,6).

Barley is one of the five most essential crop species cultivated worldwide, with a high germination rate and rapid growth in the early stages of the plant's life. In many regions of the nation, it has several potential uses that are commercially significant, including food, feed, fodder and fuel (7–9). The amount of CP, dry matter buildup, succulency and other quality parameters of fodder are all impacted by nutrient management. India has a net deficit of 23.4 % in dry fodder and 11.24 % in green fodder (7). The primary nutrient that affects the quality and productivity of herbage is nitrogen. It has been demonstrated that nitrogen fertilizer has a good correlation with fodder barley quality and production. However, in most agricultural fields, nitrogen fertilizers such as urea typically exhibit 30–40 % Nitrogen Use Efficiency (NUE) (10,11). The unused urea is discharged into the environment through various channels, contaminating the air, water and land. For example, urea contributes to air pollution and global warming by volatilizing as nitrous oxide, a greenhouse gas and being lost as ammonia gas (NH_3). In addition to nitrogen, zinc deficiency in soil has been documented by numerous researchers worldwide (12,13). Zinc deficiencies affect 63 % of soils in India (14). This reduces the quantity

and quality of barley when grown in zinc-deficient soils, as most Indian soils are zinc deficient (15). Zinc fertilization profoundly has a significant impact on improving the morphological traits, dry matter yield and CP content (16).

Numerous studies have shown direct correlations between soil micronutrients and those in fodder and forage, as is also the case with zinc. Research on nanoscale or nanotechnology, is currently enabling improved nutrient use efficiency and boosting crop production at reduced environmental contamination costs (17). Nanotechnology can potentially transform agricultural systems to address the issues like poor yield, soil degradation and the environmental impact of conventional agricultural practices (18). This would allow for the gradual and regulated release of nutrients for the benefit of plants, ultimately boosting crop yields with minimal adverse effects on the environment (19). By reducing nitrogen leaching, emissions and long-term assimilation by soil microorganisms, nano-urea can offer fertilizers that supply nitrogen when crops need it, thus increasing NUE (20).

Therefore, this study was conducted to evaluate the response of barley fodder in terms of fodder yield and quality to the application of nano-fertilizer along with zinc fertilization. The study also focuses on the effect of nano-urea and zinc application on selected soil properties.

Materials and Methods

The field trial was carried out during the rabi season of 2022–23 at the Agronomy Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India. The study area is located at 31°22' N latitude and 75°23' E longitude and is 252 m above mean sea level. Standard weekly meteorological data of maximum and minimum temperature (T, °C), Relative Humidity (RH, %), evaporation (mm day⁻¹) and rainfall (mm day⁻¹) for the growing seasons was recorded at the weather station from the meteorological observatory at Lovely Professional University, Phagwara, Punjab (Fig. 1). Before the commencement of experiment, soil samples were randomly extracted from the experimental site using an auger at 0 to 15 cm depth. The initial physicochemical properties are presented in Table 1. The study was

Table 1. Initial soil physical and chemical properties of the study site

Particular	Value	Method employed
Physical properties		
Sand (%)	45.6	International pipette method (21)
Silt (%)	22.1	
Clay (%)	32.3	
Textural class	Sandy clay loam	
Chemical properties		
EC (dS m ⁻¹)	0.3	EC bridge (22)
pH	8.05	pH meter (21)
Organic carbon (%)	0.52	Walkley and Black's wet oxidation method (22)
Available N (kg ha ⁻¹)	151	Alkaline permanganate method (23)
Available P ₂ O ₅ (kg ha ⁻¹)	35	Olsen's method (24)
Available K ₂ O (kg ha ⁻¹)	124	Flame photometer method (22)
Zinc (ppm)	0.39	DTPA-CaCl ₂ -TEA method (25)

carried out in a split-plot design and replicated thrice. There was a total of 42 plots, with a gross plot size of 5 m × 4 m. The main plot included two varieties of barley (PL 172 and PL 426); subplots consisted of seven nutrient management strategies (Table 2). The nano spray of urea (N) and foliar spray of zinc were given at 20 Days After Sowing (DAS) (1st spray) and 40 DAS (2nd spray) respectively.

Commercial nano-urea containing 4% N was obtained from Indian Farmers Fertilizer Cooperative Limited (IFFCO) and was applied in combination with zinc in this study. Fertilizers were applied as per the treatments. Urea (46% N), DAP (16% N and 48% P₂O₅) and MOP (60% K₂O) were used as fertilizer sources. Seeds of both barley varieties were treated with Zinc-solubilizing bacteria (Znsb) an hr before seeding at 5 g kg⁻¹ of barley seeds. Barley grains at a seed rate of 120 kg ha⁻¹ were treated with Znsb, manually sown on

Table 2. Treatment details

Main plot: Barley varieties	Subplot: Nutrient management
V ₁ : PL 172	T ₁ : Control
V ₂ : PL 426	T ₂ : 50% RDN + 2 nano-urea sprays + 2 sprays of zinc
	T ₃ : Absolute control + ZNSB seed treatment
	T ₄ : 75% RDN + 1 nano-urea spray + 1 spray of zinc
	T ₅ : 50% RDN + 1 nano-urea spray + 1 spray of zinc
	T ₆ : 75% RDN + 2 nano-urea sprays + 2 sprays of zinc
	T ₇ : 100% RDN

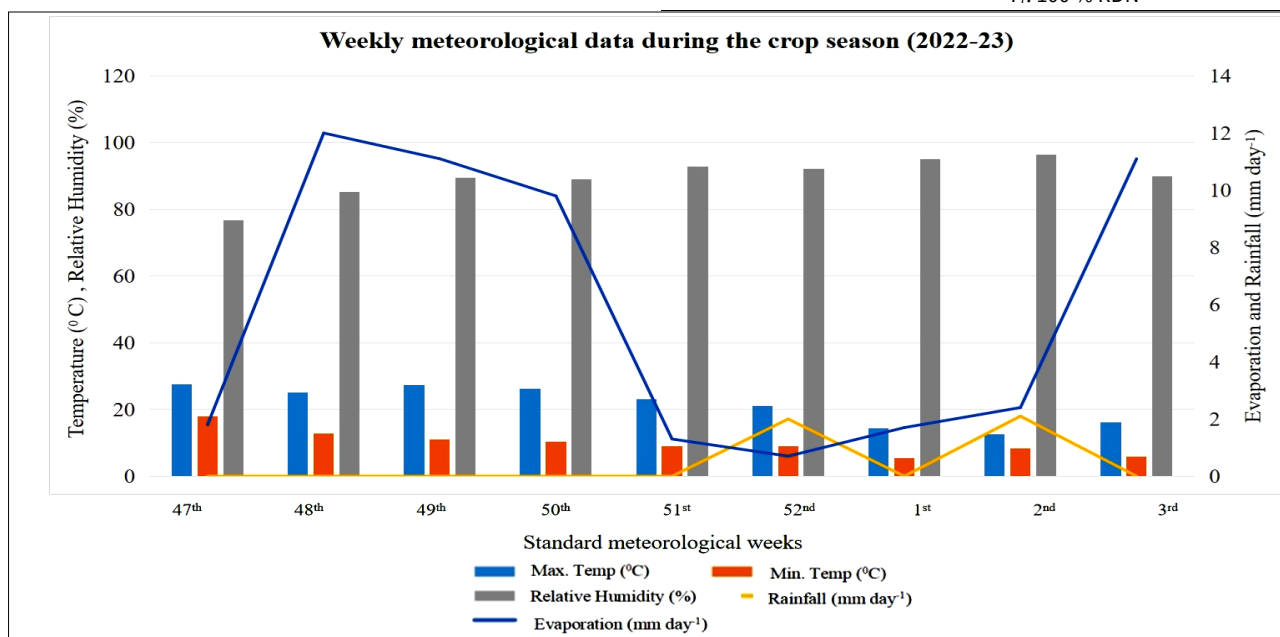


Fig. 1. Standard weekly meteorological data during the growing season (2022–23).

the 22nd of November 2022 and covered with soil. The standard cultural practices for growing barley were applied according to the Ministry of Agriculture's recommendations.

Fodder barley was harvested at 60 DAS. First, the plants in the border rows were harvested to prevent the border effect. Next, the plants in the net plot area were harvested and the fresh forage production was noted. Samples of green fodder were dried at $65 \pm 5^\circ$ C in a hot air oven until they reached a consistent weight. The dry fodder yield was calculated based on the difference between fresh and dry weights to determine moisture loss. The chemical composition was ascertained for every homogenised sample by measuring the dry matter, CP, ash and crude fiber content. The dry matter content was ascertained by drying the materials for 48 hr at 103° C. The CP content of the samples was determined using the Kjeldahl procedure. The CP (%) was then calculated by multiplying the obtained N content by a factor of 6.25. The sub-sample was burned in a muffle oven at 550° C for 3 hr and the Association of Official Analytical Chemists (AOAC) method was used to estimate the ash content. The phenol-sulfuric acid technique, was used to determine the Total Carbohydrate (TC) content (26).

Following harvest, an auger was used to remove soil samples from the top 30 cm of the soil and analyze specific soil characteristics. To determine the accessible nitrogen concentration of soil, K_2SO_4 (1 %) was used (22). Available phosphorus (P) and potassium (K) were extracted using the ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) method and the results were calculated (27). DTPA Zn was determined by extracting 10 g of soil with 20 mL of DTPA solution (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M triethanolamine) (25). After 2 hr of continuous shaking at room temperature, the soil suspension was centrifuged and filtered. The zinc concentration in the extract was determined using an Atomic Absorption Spectrometer (AAS).

Statistical analyses were performed using R Studio. Analysis of Variance (ANOVA) was used to calculate the means and significant differences between various treatments. A significance level of $p = 0.05$ was employed to compare the treatment means.

Results and Discussion

Performance of green and dry fodder yield ($t\ ha^{-1}$)

The results showed that different varieties and nutrient management strategies had a significant impact on the Green Fodder Yield (GFY) and Dry Fodder Yield (DFY) of fodder barley (Table 3). Regarding the barley varieties, PL 172 showed the highest GFY and DFY ($19.2\ t\ ha^{-1}$, $3.87\ t\ ha^{-1}$, respectively) compared to the PL 426 variety. Among various nutrient

Table 3. Effect of varieties and nutrient management on GFY and DFY ($t\ ha^{-1}$) of barley

Treatments	GFY ($t\ ha^{-1}$)	DFY ($t\ ha^{-1}$)
Varieties		
V ₁ : PL 172	19.2	3.87
V ₂ : PL 426	17.5	3.56
C.D. (0.05)	0.68	0.03
Nutrient management		
T ₁ : Control	16.8	2.70
T ₂ : 50 % RDN + 2 nano-urea sprays + 2 spray of zinc	18.9	4.15
T ₃ : Absolute control + ZnSB seed treatment	16.9	2.78
T ₄ : 75 % RDN + 1 nano-urea spray + 1 spray of zinc	18.9	4.20
T ₅ : 50 % RDN + 1 nano-urea spray + 1 spray of zinc	18.5	3.86
T ₆ : 75 % RDN + 2 nano-urea sprays + 2 sprays of zinc	19.3	4.27
T ₇ : 100 % RDN	18.7	4.05
C.D. (0.05)	0.41	0.07

management strategies, combined application of 75 % RDN, two sprays of nano-urea and two sprays of zinc (T₆) resulted in significantly higher GFY ($19.3\ t\ ha^{-1}$) and DFY ($4.27\ t\ ha^{-1}$). It was statistically similar to T₄ (75 % RDN + 1 nano-urea spray + 1 spray of Zn) treatment. Higher GFY and consistent dry matter accumulation could result in increased dry fodder production. The number of tillers per plant and the yield of barley green fodder were positively connected with the dry matter production (7). In wheat, applying nano-fertilizer greatly improved plant growth and yield metrics; plant height was significantly enhanced by the combined foliar application of nano-urea and soil application of NPK and Zn (28).

Quality parameters

The effects of different varieties and nutrient management practices on CP, crude fibre, total ash content and TC content are presented in Table 4. Significantly higher values for CP, ash content, crude fiber and TC content were obtained under the variety PL-172. Different nutrient management approaches have also been found to significantly impact the improvement of the quality aspects of fodder barley. It was observed that significantly higher value for CP (10.3 %), ash content (12.6 %), crude fiber (24 %) and TC content (67.1 %) was recorded with the application of 75 % Recommended Dose of Nitrogen (RDN) + 2 nano-urea sprays + 2 sprays of zinc (T₆).

It was found that there was a significant interaction between the different varieties under consideration and nutrient management strategies (Fig. 2 & 3). For example, when V₁ interacted with T₆, significant improvement in CP (10.9 %) and TC content (68.6 %) was obtained (Table 5 & 6).

Table 4. Effect of varieties and nutrient management on different quality parameters of fodder barley

Treatments	CP (%)	Crude fibre (%)	Ash content (%)	TC content (%)
Varieties				
V ₁ : PL 172	7.28	20.7	11.6	61.2
V ₂ : PL 426	5.92	18.7	11.3	60.6
C.D. (0.05)	0.20	0.27	0.05	0.08
Nutrient management				
T ₁ : Control	3.50	15.3	10.5	52.6
T ₂ : 50 % RDN + 2 nano urea sprays + 2 sprays of zinc	8.58	21.0	11.6	63.0
T ₃ : Absolute control + ZnSB seed treatment	3.52	15.9	10.7	55.8
T ₄ : 75% RDN + 1 nano urea spray + 1 spray of zinc	7.6	21.5	11.8	64.3
T ₅ : 50 % RDN + 1 nano urea spray + 1 spray of zinc	5.11	19.2	11.3	60.4
T ₆ : 75 % RDN + 2 Nano urea sprays + 2 sprays of zinc	10.3	24.0	12.6	67.1
T ₇ : 100 % RDN	7.62	20.7	11.6	63.0
C.D. (0.05)	0.21	0.44	0.24	1.26

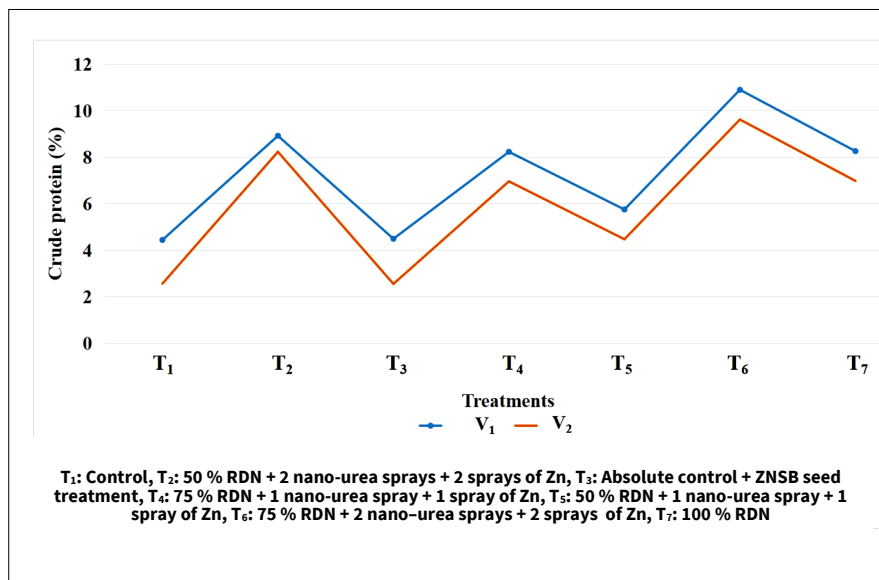


Fig. 2. Graphical representation of the interaction effect of varieties and nutrient management on CP (%) of barley at harvest.

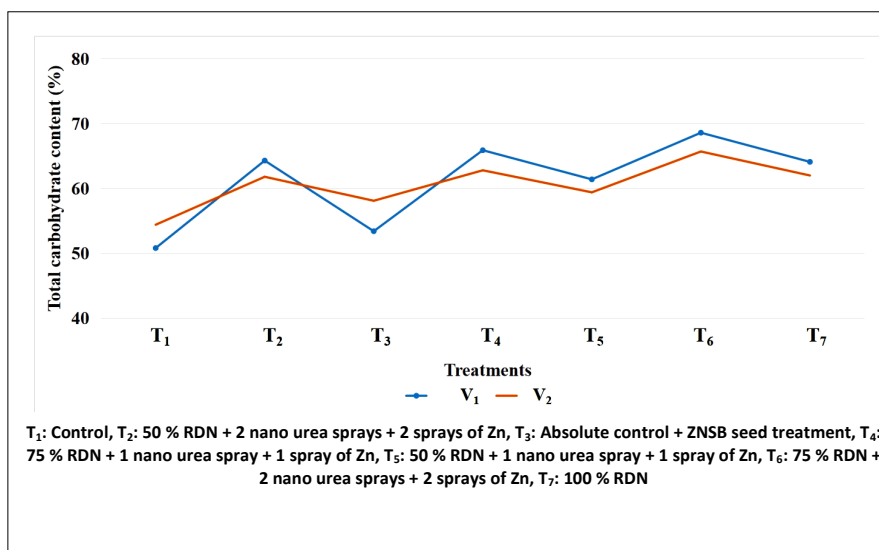


Fig. 3. Graphical representation of the interaction effect of varieties and nutrient management on TC content (%) of barley at harvest.

Table 5. Interaction effect of varieties and nutrient management on CP (%) of barley at harvest

Treatments	V1	V2	Mean
T1: Control	4.44	2.56	3.50
T2: 50 % RDN + 2 nano urea sprays + 2 sprays of zinc	8.92	8.23	8.57
T3: Absolute control + ZnSB seed treatment	4.49	2.55	3.52
T4: 75 % RDN + 1 nano urea spray+1 spray of zinc	8.23	6.96	7.6
T5: 50 % RDN + 1 nano urea spray+1 spray of zinc	5.75	4.47	5.11
T6: 75 % RDN + 2 nano urea sprays +2 sprays of zinc	10.9	9.62	10.2
T7: 100 % RDN	8.26	6.98	7.63
Mean	7.28	5.91	6.59
C.D. (0.05)		0.30	

Table 6. Interaction effect of varieties and nutrient management on TC content (%) of barley at harvest

Treatments	V1	V2	Mean
T1: Control	50.8	54.4	52.6
T2: 50 % RDN + 2 nano urea sprays + 2 sprays of zinc	64.3	61.8	63.0
T3: Absolute control + ZnSB seed treatment	53.4	58.1	55.8
T4: 75 % RDN + 1 nano urea spray + 1 spray of zinc	65.9	62.8	64.3
T5: 50 % RDN + 1 nano urea spray + 1 spray of zinc	61.4	59.4	60.4
T6: 75 % RDN + 2 nano urea sprays + 2 sprays of zinc	68.6	65.7	67.1
T7: 100 % RDN	64.1	62.0	63.0
Mean	61.2	60.6	60.9
C.D. (0.05)		1.78	

Genetic predisposition plays a key role in permitting more nutritional diversion towards creating dry matter. This may result from the combination of RDN fertilizer, zinc and urea nano sprays, which increase the availability of NPK and Zn and enhance other nutrient absorption to enhance the mineral content of plant sap (29). Similarly, barley fertilization with nitrogen increased the supply of N to crops, causing better extraction and as a result, maximum accumulation of nitrogen in plant tissue, which contributed to increased CP content in green fodder (30). Similar results were reported in barley (31-33). The application of nitrogen to crop plants resulted in higher absorption, which in turn led to increased nitrogen buildup in plants, contributing to the CP content. This made the rise in CP content of the fodder evident (32).

Large levels of carbohydrates in fodder plants like maize are preferable to high levels of lignin. They digest quite readily and supply easily accessible energy (34). The amount of nutrients applied increases the availability of nutrient content by the plants for their development, photosynthesis and metabolic processes. Reduced nutrient availability often leads to impaired photosynthesis and decreased carbohydrate synthesis due to metabolic stress.

Available nutrient status of the soil after harvest

The data relating to the available N, P and Zn status of soil (Table 7) revealed that the barley varieties did not significantly alter the post-harvest levels of N, P and Zn in soil. However, different nutrient management strategies were found to have a profound effect on the final soil nutrient status. The highest available N and P levels were recorded under T6 treatment, indicating improved nutrient retention. Significantly higher yet statistically similar values for available zinc content in soil were noticed in T₂, T₆ and T₇, respectively. This might be because nutrient management with the inclusion of nano-fertilizer improves the availability of the final nutrient content in soil (35-37).

Conclusion

It was confirmed from the present experimental study that different varieties, along with nutrient management approaches with the inclusion of nano-urea, facilitate the gradual and sustained release of nutrients to plants, thereby improving the yield and quality aspects of fodder barley. Using nanotechnology to reduce the use of conventional fertilizer can be considered an environmentally friendly

approach. Therefore, growing PL 172 variety with application of 75% RDN + two nano urea sprays + two sprays of zinc can effectively enhance the GFY, DFY and the nutritive value of fodder barley.

Acknowledgements

The authors thank Lovely Professional University, School of Agriculture, for providing the necessary infrastructure and resources.

Authors' contributions

Conceptualization, supervision, editing and final drafting were carried out by RKG, PP and AM, while experimentation and manuscript writing were performed by PP, AM, PT and MA and data recording by ZTA, RS and S. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

- Singh DN, Bohra JS, Tyagi V, Singh T, Banjara TR, Gupta G. A review of India's fodder production status and opportunities. *Grass Forage Sci.* 2022;77:1-10. <https://doi.org/10.1111/gfs.12561>
- Kashyap S, Kumar R, Ram H, Kumar A, Basak N, Sheoran P, et al. Quantitative and qualitative response of fodder maize to use of bulk and nano-fertilizers in northwestern plains of India. *Agronomy.* 2023;13:1889. <https://doi.org/10.3390/agronomy13071889>
- Singh A. *Livestock production statistics of India-2021.* New Delhi: Department of Animal Husbandry and Dairying; 2021. p. 1-48.
- Patel D, Ponnusamy K, Sendhil R. Development and testing of potential indicators for evaluation of dairy production systems. *Indian J Anim Sci.* 2019;89:1274-82. <https://doi.org/10.56093/ijans.v89i11.95890>
- Indian Grassland and Fodder Research Institute. *Vision 2050.* Jhansi; 2015. p. 7-23.
- Sarabia-Salgado L, Solorio-Sánchez F, Ramírez-Avilés L, Alves BJR, Ku-Vera J, Aguilar-Pérez C, et al. Increase in milk yield from cows through improvement of forage production using the N₂-fixing legume *Leucaena leucocephala* in a silvopastoral system. *Animals.* 2020;10:734. <https://doi.org/10.3390/ani10040734>

Table 7. Effect of varieties and nutrient management on nitrogen, phosphorus and zinc content in soil after harvest

Treatments	Nitrogen (kg ha ⁻¹)	Phosphorus (kg ha ⁻¹)	Zinc (ppm)
Varieties			
V ₁ : PL 172	140.30	35.9	0.218
V ₂ : PL 426	142.31	34.5	0.210
C.D. (0.05)	NS	NS	NS
Nutrient management			
T ₁ : Control	108.7	28.6	0.21
T ₂ : 50 % RDN + 2 nano urea sprays + 2 sprays of zinc	155.7	35.5	0.22
T ₃ : Absolute control + ZnSB seed treatment	112.9	29.1	1.10
T ₄ : 75 % RDN + 1 nano urea spray +1 spray of zinc	154.2	38.5	0.21
T ₅ : 50 % RDN + 1 nano urea spray + 1 spray of zinc	147.6	35.8	0.21
T ₆ : 75 % RDN + 2 nano urea sprays + 2 sprays of zinc	160.3	39.4	0.22
T ₇ : 100 % RDN	150.5	39.6	0.22
C.D. (0.05)	2.98	0.72	0.05

7. Kumar S, Kumar N, Satpal PK, Kharor N, Dahiya P. Effect of nano-urea on sustainable production of fodder sorghum. *Forage Res.* 2024;50:70-6.
8. Potokina E, Sreenivasulu N, Altschmied L, Michalek W, Graner A. Differential gene expression during seed germination in barley (*Hordeum vulgare* L.). *Funct Integr Genomics.* 2002;2:28-39. <https://doi.org/10.1007/s10142-002-0050-x>
9. Abdi N, Wasti S, Salem MB, El Faleh M, Mallek-Maalej E. Study on germination of seven barley cultivars (*Hordeum vulgare* L.) under salt stress. *J Agric Sci.* 2016;8:88-97. <https://doi.org/10.5539/jas.v8n8p88>
10. Shivay YS, Prasad R, Mandi S. Plants, fertilizer nitrogen and environment: an overview. *Int J Plant Environ.* 2020;6:98-102.
11. Sapkota TB, Bijay-Singh, Takele R. Improving nitrogen use efficiency and reducing nitrogen surplus through best fertilizer nitrogen management in cereal production: the case of India and China. *Adv Agron.* 2023;178:233-94. <https://doi.org/10.1016/bs.agron.2022.11.006>
12. Alloway BJ. Zinc in soils and crop nutrition. 2nd ed. Brussels: IZA and IFA; 2008
13. Noulas C, Tziouvalekas M, Karyotis T, Das PK, Mohanty S, Dash D. Impact of integrated nutrient management on soil phosphorus dynamics in peanut (*Arachis hypogaea*). *J Soil Sci Plant Nutr.* 2020;20:590-601.
14. Arunachalam P, Kannan P, Prabukumar G, Govindaraj M. Zinc deficiency in Indian soils with special focus to enrich zinc in peanut. *Afr J Agric Res.* 2013;8:6681-8.
15. Srinivasarao CH, Rani YS. Zinc deficiency: a productivity constraint in rainfed crop production systems of India. *J SAT Agric Res.* 2013;11:1-8.
16. Sher A, Ul-Allah S, Sattar A, Ijaz M, Qayyum A, Manaf A, et al. Zinc sulfate application to grass forages (oat, barley, annual ryegrass and triticale) for increasing their yield, quality and profitability. *Crop Pasture Sci.* 2022;73:473-83. <https://doi.org/10.1071/CP21476>
17. Shekara B, Chikkarugi NM, Rani N. Influence of nano-urea on productivity and quality of fodder oat (*Avena sativa* L.) in southern dry zone of Karnataka. *Mysore J Agric Sci.* 2024;58(4):312-9.
18. Saitheja V, Senthivelu M, Prabukumar G, Prasad V. Maximizing the productivity and profitability of summer irrigated greengram (*Vigna radiata* L.) by combining basal nitrogen dose and foliar nutrition of nano and normal urea. *Int J Plant Soil Sci.* 2022;34:109-16. <https://doi.org/10.9734/ijpss/2022/v34i2231362>
19. Scott N, Chen H. Nanoscale science and engineering for agriculture and food systems. *Ind Biotechnol.* 2012;8:340-3. <https://doi.org/10.1089/ind.2012.1549>
20. Kanno J, Jain D, Tomar M, Patidar R, Choudhary R. Effect of nano urea vs conventional urea on the nutrient content, uptake and economics of black wheat (*Triticum aestivum* L.) along with biofertilizers. *Biol Forum.* 2022;14:499-504.
21. Piper CS. Soil and plant analysis. Bombay: Hans Publishers; 1966. p. 294-6
22. Jackson ML. Soil chemical analysis. New Delhi: Prentice-Hall of India; 1967
23. Subbiah BV, Asija GL. A rapid procedure for determination of available nitrogen in soil. *Curr Sci.* 1956;25:259-60.
24. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *USDA Circular.* 1954;939:1-19.
25. Lindsay WL, Norvell W. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci Soc Am J.* 1978;42(3):421-8. <https://doi.org/10.2136/sssaj1978.03615995004200030009x>
26. DuBois M, Gilles KA, Hamilton JK, Rebers PA, Smith F. Colorimetric method for determination of sugars and related substances. *Anal Chem.* 1956;28(3):350-6. <https://doi.org/10.1021/ac60111a017>
27. Soltanpour PN. Use of ammonium bicarbonate DTPA soil test to evaluate elemental availability and toxicity. *Commun Soil Sci Plant Anal.* 1985;16(3):323-38. <https://doi.org/10.1080/00103628509367607>
28. Gangwar SK, Singh RP, Mishra PK, Ahmad R, Singh AK. Effect of foliar application of nano-fertilizers on growth and yield of wheat (*Triticum aestivum* L.). *Adv Biores.* 2022;13:190-3.
29. Reddy KS, Shivay YS, Kumar D, Pooniya V, Prasanna R, Shrivastava M, et al. Relative performance of urea and nano-urea in conjunction with zinc fertilization on growth, productivity and nitrogen use efficiency in spring wheat. *J Soil Sci Plant Nutr.* 2024;24:3593-609. <https://doi.org/10.007/s42729-024-01780-3>
30. Singh R, Singh RK. Effect of time and levels of nitrogen application on malt barley (*Hordeum vulgare* L.). *Indian J Agron.* 2005;50:137-9. <https://doi.org/10.59797/ija.v50i2.5085>
31. Hadi F, Hussain F, Arif M. Effect of different nitrogen levels and cutting on growth behavior of dual purpose barley. *Emergence.* 2012;1000:2-8.
32. Choudhary KK, Yadava NS, Yadav SL, Jat RC. Green fodder yield and quality of barley (*Hordeum vulgare* L.) as affected by levels of nitrogen. *Forage Res.* 2014;39:190-6.
33. Pandey AK, Singh M, Kumar S, Meena VK, Onte S, Kushwaha M. Influence of stage of harvesting and zinc application on yield and zinc uptake in cluster bean [*Cyamopsis tetragonoloba* (L.) Taub]. *Legume Res.* 2019;42:661-5. <https://doi.org/10.18805/LR-4113>
34. Hanif NQ, Akhtar N. Nutritional evaluation of maize plant fodder grown in spring and autumn season in Punjab, Pakistan. *J Bioresour Manage.* 2020;7:9-16. <https://doi.org/10.35691/JBM.0202.0123>
35. Ramesh A, Singh M, Yadav MR. Influence of nano fertilizers on nutrient dynamics and yield of cereals. *Agron J.* 2019;111:657-65.
36. Das PK, Mohanty S, Dash D. Impact of integrated nutrient management on soil phosphorus dynamics in peanut (*Arachis hypogaea*). *J Soil Sci Plant Nutr.* 2020;20:590-601.
37. Yadav R, Sharma P, Singh S. Efficacy of nano fertilizers on soil nutrient status and phosphorus uptake in soybean. *Int J Plant Prod.* 2021;15:431-44.

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.