International Journal of Agriculture and Food Science 2026; 8(6): 439-442

ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(6): 439-442
www.agriculturaljournals.com
Received: 05-04-2026
Accepted: 07-05-2026

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Optimization of Nitrogen and Zinc Fertilization for Enhancing Growth and Yield in Sorghum (*Sorghum bicolor* L.) Varieties

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DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i6f.1626

Abstract
A field experiment was conducted during the Kharif season of 2025 at the Research Farm, Department of Agriculture, Vivekananda Global University, Jaipur, Rajasthan. Sorghum is an important cereal crop cultivated in arid and semi-arid regions due to its drought tolerance, nutritional value, and adaptability to adverse climatic conditions. Efficient nutrient management, particularly nitrogen and zinc fertilization, plays a vital role in improving sorghum productivity and nutrient-use efficiency. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. Treatments comprised different levels of recommended fertilizer dose (RDF) combined with zinc sulphate ($ZnSO_4$) applied through soil and foliar methods. The sorghum variety CSV-15 was used for the study.

The results revealed that nutrient management significantly influenced growth and yield parameters of sorghum. The treatment T_9 (125% RDF + $ZnSO_4$ foliar application) recorded the maximum plant height at harvest (165.2 cm), highest grain yield (3912 kg ha^{-1}), biological yield (12,292 kg ha^{-1}), 100-grain weight (27.5 g), and harvest index (32.82%). Foliar application of zinc in combination with higher nitrogen levels proved more effective than soil application in enhancing nutrient uptake, vegetative growth, and yield attributes. The control treatment recorded the lowest values for most parameters. The study concluded that application of 125% RDF along with foliar $ZnSO_4$ significantly improved growth, productivity, and nutrient-use efficiency of sorghum under semi-arid conditions. Therefore, integrated nitrogen and foliar zinc management can be recommended for achieving higher sorghum yield and sustainable crop production in Rajasthan and similar agro-climatic regions.

Keywords: Nitrogen and Zinc Fertilization

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereal crops of the world and belongs to the family *Poaceae*. Originating in northeastern Africa, particularly Ethiopia and Sudan, sorghum has been cultivated for centuries and plays a vital role in ensuring food, fodder, and nutritional security, especially in arid and semi-arid regions. Due to its deep root system, efficient water-use capacity, and tolerance to high temperatures, sorghum is often referred to as the “camel crop” and is considered highly resilient to climate change. The crop serves multiple purposes, including human consumption, livestock feed, fodder, and industrial uses such as biofuel production and brewing. Globally, sorghum is cultivated on approximately 40–42 million hectares with an annual production of 60–65 million tonnes. India is among the leading sorghum-producing countries, where the crop occupies about 4.5–5.0 million hectares and contributes significantly to dryland agriculture. Apart from being a staple food in several regions, sorghum has recently gained prominence as a “nutri-cereal” owing to its gluten-free nature, high dietary fibre content, and rich supply of essential minerals and antioxidants.

Nutrient management is a critical factor influencing sorghum productivity. Among the essential nutrients, nitrogen plays a pivotal role in plant growth, chlorophyll synthesis, protein formation, and yield development. Adequate nitrogen supply enhances vegetative growth, photosynthetic efficiency, and grain production.

Similarly, zinc is an important micronutrient involved in enzyme activation, hormone synthesis, and metabolic processes. Zinc deficiency, which is widespread in Indian soils, particularly in sandy and alkaline soils, often limits sorghum growth and productivity.

Efficient management of nitrogen and zinc is therefore essential for achieving higher productivity and nutrient-use efficiency in sorghum. Optimizing the application of these nutrients can improve crop growth, yield attributes, grain yield, and profitability while contributing to sustainable agricultural production under changing climatic conditions.

Material and methods

The experimental site is situated in a semi-arid region with a subtropical climate characterized by hot summers, moderate rainfall, and abundant sunshine during the crop growth period. The soil of the experimental field was loamy sand in texture, low in organic carbon (0.22%), and contained 127.50, 20.22, and 157.75 kg ha^{-1} of available nitrogen, phosphorus, and potassium, respectively, with an electrical conductivity of 1.33 dS m^{-1}. The experiment was laid out in a Randomized Block Design (RBD) comprising nine treatments and three replications. Treatments consisted of different levels of recommended fertilizer dose (RDF) in combination with zinc sulphate ($ZnSO_4$) applied either through soil or foliar methods. The sorghum variety CSV-15 was sown during the third week of June using a seed rate of 8 kg ha^{-1} at a spacing of 45 cm × 15 cm. The gross and net plot sizes were 16.2 m² and 10.8 m², respectively. The recommended fertilizer dose of 120:60:40 kg N:P_2O_5:K_2O ha^{-1} was supplied through urea, single superphosphate, and muriate of potash. Nitrogen was applied in split doses, while zinc sulphate was applied according to the treatment schedule through soil incorporation or foliar spray. Standard agronomic practices including irrigation, thinning, weeding, and plant protection measures were followed uniformly throughout the crop season.

Observations on plant population, plant height, number of tillers per plant, grains per panicle, grain yield per plant, 100-grain weight, biological yield, grain yield, and harvest index were recorded at appropriate growth stages. The harvested produce from each plot was sun-dried, threshed, and weighed separately for yield estimation. Experimental data were subjected to analysis of variance (ANOVA) for Randomized Block Design, and treatment means were compared using the critical difference (CD) test at the 5 per cent level of significance.

Results

Plant height

The analysis of plant height across different treatment combinations of nitrogen and zinc revealed significant differences (F = 17.916; $P < 0.001$), indicating a strong influence of nutrient management on vegetative growth as shown in Table.

Asif *et al.* (2013) found that plant height increased significantly with increasing nitrogen levels, with the tallest plants observed at 300 kg N/ha, supporting the influence of nitrogen on vegetative growth. The maximum plant height of 115.88 cm was observed in Treatment 9 (125% RDF + $ZnSO_4$ foliar application), which was significantly superior to the rest of the treatments. This suggests that a higher dose of nutrients, particularly when applied foliar, promotes better shoot elongation and overall growth.

These observations are consistent with the findings of Bhatt *et al.* (2012), Asif *et al.* (2013), and RTokjy *et al.* (2021), who reported that increasing nitrogen levels and the use of foliar-applied nutrients significantly enhance plant height in sorghum due to improved chlorophyll synthesis, nutrient mobility, and vegetative growth.

Table 1: Effect of Nitrogen and zinc doses on plant height (cm) in sorghum

Treatments	Recommended doses	30 DAS	60 DAS	At harvest
T_1 (Control)	100	24.1	89.67	101.6
T_2	50% RDF+$ZnSO_4$ (Recommended)	25.4	91.19	107.5
T_3	75% RDF+$ZnSO_4$(Soil application)	27.3	93.65	110.5
T_4	100% RDF+$ZnSO_4$(Soil application)	28.9	96.56	118.7
T_5	125% RDF+$ZnSO_4$)(Soil application)	30.1	100.68	126.72
T_6	50% RDF+$ZnSO_4$(Foliar application)	31.3	108.46	134.75
T_7	75% RDF+$ZnSO_4$(Foliar application)	33.5	121.60	142.78
T_8	100% RDF+$ZnSO_4$(Foliar application)	35.4	138.52	154.79
T_9	125% RDF+$ZnSO_4$(Foliar application)	37.3	110.71	165.2
SEm±		3.629		
CV		6.557		

Grain yield per plant (g)

Data pertaining to Table revealed that the lowest grain yield (2800 kg/ha) was observed in the control (T_1) treatment and the highest yield (3912 kg/ha) was recorded in T_9 (125% RDF + $ZnSO_4$ via foliar application), showing a progressive increase in yield with higher nutrient doses and foliar applications.

Foliar application treatments (T_6–T_9) consistently performed better than soil-applied ones, indicating enhanced nutrient availability and uptake efficiency. Yield improved notably with each increase in RDF level, especially when combined with foliar $ZnSO_4$.

The highest yield was observed in T_9 (125% RDF + $ZnSO_4$ foliar), reaching 450 g per plant at harvest. R. Tokjy *et al.* (2021) found that 125% RDF combined with foliar spray of 2% NPK resulted in the highest grain and straw yields, highlighting the advantage of foliar nutrient application for yield enhancement.

Table 2: Effect of nitrogen and zinc on the Grain yield per plant of *sorghum*

Treatments	Recommended doses	Grain yield Kg/ ha.
T_1 (Control)	100	2800
T_2	50% RDF+$ZnSO_4$ (Recommended)	3050
T_3	75% RDF+$ZnSO_4$(Soil application)	3180
T_4	100% RDF+$ZnSO_4$(Soil application)	3370
T_5	125% RDF+$ZnSO_4$)(Soil application)	3480
T_6	50% RDF+$ZnSO_4$(Foliar application)	3642
T_7	75% RDF+$ZnSO_4$(Foliar application)	3665
T_8	100% RDF+$ZnSO_4$(Foliar application)	3875
T_9	125% RDF+$ZnSO_4$(Foliar application)	3912
SE(m)		2.002
C.V.		0.874

100- Grain Weight (g)

A visualization of data presented in Table revealed that the 100-grain weight of sorghum was significantly influenced by nitrogen and zinc treatments. Highest 100-grain weight (27.5 g) was recorded in T_9 (125% RDF + $ZnSO_4$ via foliar application), closely followed by T8 (27.4 g) and T7 (26.6 g). The lowest weight (21.8 g) was observed in T4 (100% RDF + $ZnSO_4$ via soil application), slightly lower than the control (T_1). Foliar applications performed significantly better than soil applications at comparable RDF levels, indicating enhanced grain filling and nutrient use efficiency. Among soil-applied treatments, T_2 (25.8 g) and T_5 (24.1 g) were better than others, likely due to moderate zinc and nitrogen synergy. The low coefficient of variation (6.374%) suggests relatively consistent performance across treatments.

Table 3: Effect of nitrogen and zinc on 100-grain weight of *sorghum*

Treatments	Recommended doses	100-grain weight (At harvest)
T_1 (Control)	100	22.7
T_2	50% RDF+$ZnSO_4$ (Recommended)	25.8
T_3	75% RDF+$ZnSO_4$(Soil application)	22.3
T_4	100% RDF+$ZnSO_4$(Soil application)	21.8
T_5	125% RDF+$ZnSO_4$)(Soil application)	24.1
T_6	50% RDF+$ZnSO_4$(Foliar application)	23.4
T_7	75% RDF+$ZnSO_4$(Foliar application)	26.6
T_8	100% RDF+$ZnSO_4$(Foliar application)	27.4
T_9	125% RDF+$ZnSO_4$(Foliar application)	27.5
SE(m)		0.91
C.V.		6.374

Biological Yield (kg/ha)

Data pertaining to Table revealed that the highest biological yield (12120 kg/h) was observed in T_9 (125% RDF + $ZnSO_4$ via foliar application). The lowest biological yield (99000 kg/h) was recorded in the control (T_1), reflecting the absence of supplemental nutrients. Treatments with soil application showed intermediate yield responses, with T_5 (11255 kg/h) being the best among them. These findings are supported by Mundhe *et al.* (2022), and Kumar *et al.* (2022) [5, 9], who also reported that increased nitrogen levels and foliar application of micronutrients significantly improve biological yield in sorghum by enhancing dry matter production and nutrient assimilation.

Table 4: Effect of nitrogen and zinc on the Biological Yield of *sorghum*

Treatments	Recommended doses	Biological Yield (Kg/ha)
T_1 (Control)	100	9,900
T_2	50% RDF+$ZnSO_4$ (Recommended)	10,250
T_3	75% RDF+$ZnSO_4$(Soil application)	10,570
T_4	100% RDF+$ZnSO_4$(Soil application)	10,950
T_5	125% RDF+$ZnSO_4$)(Soil application)	11,255
T_6	50% RDF+$ZnSO_4$(Foliar application)	11,532
T_7	75% RDF+$ZnSO_4$(Foliar application)	11,755
T_8	100% RDF+$ZnSO_4$(Foliar application)	12,120
T_9	125% RDF+$ZnSO_4$(Foliar application)	12,292
SE(m)		2.73
C.V.		0.595

Harvest Index (%)

A perusal of data presented in Table revealed that the highest harvest index was observed in T9 (32.82%), closely followed by T8 (31.97%), both under foliar $ZnSO_4$ application and the lowest harvest index (28.28%) was recorded in T_6 (50% RDF + $ZnSO_4$ Foliar), indicating that very low foliar input might not be as effective. Among soil-applied treatments, T5 showed a reasonably high value (30.91%), suggesting that increasing $ZnSO_4$ dosage improves partitioning of biomass towards grain production.

The control (T_1) and low-dose treatments (T_2) had moderate harvest index values, indicating a gradual improvement with increasing fertilizer levels. The data suggest that balanced foliar applications of Zn and N promote better physiological efficiency, reflected in higher harvest index.

Table 5: Effect of nitrogen and zinc on the Harvest Index of *sorghum*

Treatments	Recommended doses	Harvest index
T_1 (Control)	100	28.28
T_2	50% RDF+$ZnSO_4$ (Recommended)	29.75
T_3	75% RDF+$ZnSO_4$(Soil application)	30.08
T_4	100% RDF+$ZnSO_4$(Soil application)	30.77
T_5	125% RDF+$ZnSO_4$)(Soil application)	30.91
T_6	50% RDF+$ZnSO_4$(Foliar application)	31.58
T_7	75% RDF+$ZnSO_4$(Foliar application)	31.17
T_8	100% RDF+$ZnSO_4$(Foliar application)	31.97
T_9	125% RDF+$ZnSO_4$(Foliar application)	32.82
SE(m)		0.996
C.V.		3.431

Conclusion

Application of different fertilizer combinations had no significant impact on the initial plant population, indicating uniform crop establishment across treatments.

The tallest plants at 30, 60 DAS and harvest stages were recorded in the treatment T_9 (125% RDF + $ZnSO_4$ foliar application), signifying enhanced vegetative growth due to higher nitrogen availability and efficient zinc absorption.

Dry matter accumulation increased with increasing fertilizer dose and zinc supplementation. Foliar application of ZnSO4 at higher RDF levels (especially T9 and T8) showed superior performance compared to soil-applied or lower dose treatments.

Effect on Yield and Yield Attributes

Treatments with foliar application of $ZnSO_4$ and elevated RDF levels significantly improved yield attributes such as ear length, ear girth, number of tillers per plant, number of grains per cob, 100-grain weight, and grain yield per plant. The maximum performance was observed in T_9, followed by T_8.

The highest grain yield (3912 kg/ha), stover yield (8,380 kg/ha), and biological yield (12120 kg/ha) were obtained in T9, which was statistically superior to the control and lower fertilizer treatments.

Harvest index remained relatively stable across treatments, indicating that the proportional distribution of biomass between grain and stover did not change significantly with nutrient treatments.

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