



RESEARCH ARTICLE

# Influence of zinc application on biomass yield, nutrient uptake and economics of multicut fodder sorghum varieties

Sudha Verma\*, Manpreet Kour, Vijay Kumar, Bhim Singh, Ankita Kumari Bhagat, Mahesh Namdev Singhare, Himani Sharma, Vivek Bhagat, Yogesh Kumar, Vishal Dubey & Ranjana Mankotia

Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu and Kashmir, India

\*Correspondence email - [sudhaverma2000@gmail.com](mailto:sudhaverma2000@gmail.com)

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## Abstract

A field experiment was conducted during the kharif season of 2023 at the Research Farm, Division of Agronomy, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, to evaluate the impact of zinc (Zn) fertilization on biomass yield, nutrient uptake and economic returns of multicut fodder sorghum varieties. The experimental soil was sandy clay loam, slightly alkaline in nature, low in organic carbon, nitrogen (N) and Zn, but medium in available phosphorus (P) and potassium (K). The experiment was laid out in a Factorial Randomized Block Design (FRBD) with 3 replications, comprising 2 sorghum varieties (SSG and CSV 33MF) and 8 Zn treatments, viz., F<sub>1</sub>- Recommended Dose of Fertilizer (RDF), F<sub>2</sub>- RDF + soil application of zinc sulfate (ZnSO<sub>4</sub>) at 20 kg ha<sup>-1</sup>, F<sub>3</sub>- RDF + foliar application of ZnSO<sub>4</sub> at 0.5 % at 40 Days After Sowing (DAS), F<sub>4</sub>- RDF + foliar application of ZnSO<sub>4</sub> at 0.5 % at 80 DAS, F<sub>5</sub>- RDF + foliar application of ZnSO<sub>4</sub> at 0.5 % at 40 DAS and 80 DAS, F<sub>6</sub>- RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar application of ZnSO<sub>4</sub> at 0.5 % at 40 DAS, F<sub>7</sub>- RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar application of ZnSO<sub>4</sub> at 0.5 % at 80 DAS and F<sub>8</sub>- RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + Foliar application of ZnSO<sub>4</sub> at 0.5 % at 40 DAS and 80 DAS. A uniform basal dose of nitrogen: phosphorus pentoxide: potassium oxide (N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O) at 60:40:20 kg ha<sup>-1</sup> was applied across treatments. Results revealed that CSV 33MF recorded significantly higher total green biomass yield, nutrient uptake and crude protein content across all harvests. However, the highest net returns and benefit-cost ratio were observed in the SSG variety. Among Zn treatments, the combined application of RDF + ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> to soil and foliar sprays of 0.5 % ZnSO<sub>4</sub> at 40 and 80 DAS (F<sub>8</sub>) significantly improved biomass yield and nutrient uptake parameters. F<sub>8</sub> (RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar application of ZnSO<sub>4</sub> at 0.5 % at 40 DAS and 80 DAS) also showed superior economic performance. Based on the findings, CSV 33MF in combination with RDF + ZnSO<sub>4</sub> soil application and foliar sprays appears to be the most effective strategy for enhancing biomass yield, fodder quality and nutrient use. However, SSG with the same treatment maximized economic returns.

**Keywords:** biomass yield; crude protein; economic returns; nutrient uptake; zinc fertilization

## Introduction

Fodder sorghum (*Sorghum bicolor* L. Moench) is one of the most important forage crops grown in India, particularly during the kharif season, due to its high biomass production, multicut nature, drought tolerance and adaptability across diverse agro-climatic conditions (1,2). As livestock farming continues to expand, the demand for quality green fodder is increasing rapidly. Among the various fodder types, multicut sorghum varieties (type or variety of sorghum that can be harvested (cut) multiple times from the same planting) have gained popularity due to their ability to regenerate after cutting, offering multiple harvests in a single season with substantial green biomass and acceptable nutritive value (3,4).

Despite the genetic potential of improved varieties, the productivity and nutritive quality of fodder sorghum are often constrained by poor soil fertility, especially micronutrient deficiencies. Zn, an essential micronutrient, plays a critical role in enzyme activation, chlorophyll synthesis and protein metabolism, directly influencing plant growth, nutrient uptake and forage quality (5,6). Zn deficiency is widespread in Indian soils, particularly in intensively

cultivated areas and is recognized as a major limiting factor in realizing optimum crop yield and quality (7,8). Moreover, the integration of soil and foliar application of Zn has been shown to enhance nutrient efficiency and biomass productivity in many cereal and fodder crops (9,10).

In this context, the selection of suitable multicut sorghum varieties, combined with appropriate Zn fertilization strategies, holds significant promise for enhancing green fodder production, improving nutritive value and achieving better economic returns. However, limited studies are available evaluating the combined effect of Zn application (soil and foliar) on the performance of multicut fodder sorghum under agro-climatic conditions of the North-Western Himalayan region.

Therefore, the present investigation was undertaken to assess the effect of different Zn application methods on growth, biomass yield, nutrient uptake, fodder quality and economics of 2 multicut sorghum varieties under field conditions. The findings aim to provide insights into Zn management practices for improving forage production and profitability in fodder-based cropping systems.

## Materials and Methods

### Experimental site and climatic conditions

A field experiment was conducted during the kharif season of 2023 at the Research Farm of the Division of Agronomy, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST-J), Chatha campus (32°40' N latitude and 74°82' E longitude, 332 m above mean sea level). The site lies in the subtropical Shivalik foothills of the North-Western Himalayas.

The region experiences hot, dry summers, a warm and humid monsoon and cold winters. During the cropping season, the maximum mean weekly temperature reached 37.9 °C in June and the minimum dropped to 14.2 °C in October. Relative humidity ranged from 94.7 % in August to 44.6 % in October. Approximately 75 % of the region's total annual rainfall (~1115 mm) is received during the Southwest monsoon (June–September), while the remaining 25 % falls during winter months through western disturbances (December–March).

### Experimental design and treatments

The experiment was laid out in a FRBD with 3 replications. Factor A comprised 2 multicut fodder sorghum varieties: V<sub>1</sub>: SSG and V<sub>2</sub>: CSV 33MF. Factor B included 8 Zn fertilization treatments:

- F<sub>1</sub>: RDF
- F<sub>2</sub>: RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup>
- F<sub>3</sub>: RDF + foliar spray of ZnSO<sub>4</sub> at 0.5 % at 40 DAS
- F<sub>4</sub>: RDF + foliar spray of ZnSO<sub>4</sub> at 0.5 % at 80 DAS
- F<sub>5</sub>: RDF + foliar spray of ZnSO<sub>4</sub> at 0.5 % at 40 and 80 DAS
- F<sub>6</sub>: RDF + soil application at 20 kg ha<sup>-1</sup> + foliar spray at 0.5 % at 40 DAS
- F<sub>7</sub>: RDF + soil application at 20 kg ha<sup>-1</sup> + foliar spray at 0.5 % at 80 DAS
- F<sub>8</sub>: RDF + soil application at 20 kg ha<sup>-1</sup> + foliar spray at 0.5 % at 40 and 80 DAS

The RDF was 60:40:20 kg nitrogen: phosphorus pentoxide: potassium oxide (N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O) per ha, applied uniformly across all treatments. Full doses of phosphorus (P) and potassium (K) and half of the nitrogen (N) were applied as basal; the remaining N was top-dressed in equal splits after each harvest.

The field was prepared by 2 cross harrowing's followed by a rotavator. Sowing was done using the *kera* method with 30 cm row spacing. Seeds were placed in shallow furrows and covered with soil using a light planker.

### Soil characteristics

The experimental field had a sandy clay loam texture, slightly alkaline reaction, low organic carbon and low available N and Zn (DTPA-extractable), but medium in available P and K.

### Yield observations

Green biomass yield was recorded at 60, 100 and 130 DAS. Green biomass was estimated from a 1 m<sup>2</sup> area at 3 randomly selected spots in each net plot. Fresh samples were oven-dried at 60–65 °C for 48–72 hr to determine dry matter content.

### Nutrient uptake analysis

Representative samples from each treatment were taken at each harvest for estimation of N, P, K and Zn content. Samples were oven-dried, ground and analysed using the following methods:

**Total N:** Kjeldahl method (11)

**P and K:** As per standard procedures (11)

**Zn:** Atomic absorption spectrophotometry (12)

Nutrient uptake was calculated using the formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Nutrient content (\%)} \times \text{Dry matter yield (kg ha}^{-1}\text{)} \times 100 \quad (\text{Eqn. 1})$$

### Fodder quality parameters

Plant samples were dried to constant weight in a hot air oven at 60 °C, ground and analyzed for the following quality parameters:

**Crude protein:** Using a modified micro Kjeldahl method, treatment-wise plant samples of sorghum fodder were analyzed for N concentration. The protein content of each treatment was then determined by multiplying the sorghum fodder's N content (%) by 6.25 and the result was expressed as a percentage (13).

### Economic analysis

Economic returns were computed based on prevailing market prices for inputs and outputs. Net returns and benefit-cost ratio (B:C) were calculated for each treatment to evaluate profitability.

### Statistical analysis

Data were statistically analysed using Analysis of Variance (ANOVA) (14). Treatment means were compared using the *F*-test and Critical Differences (CD) at 5 % level of significance were calculated where appropriate.

## Results and Discussion

### Yield

#### Effect of varieties on green biomass yield

The data revealed that variety CSV 33MF significantly outperformed Sorghum Sudan Grass (SSG) in terms of green biomass yield at all 3 harvests (Table 1). CSV 33MF recorded the highest total green biomass yield (63615.17 kg ha<sup>-1</sup>) compared to SSG (47175.33 kg ha<sup>-1</sup>). The increased yield in CSV 33MF could be attributed to its superior growth vigor, regeneration capacity and possibly better nutrient use efficiency, which aligns with earlier studies (15,16), reporting better performance of improved multicut sorghum genotypes in terms of fodder productivity.

#### Effect of Zn fertilization on green biomass yield

Zn fertilization had a significant influence on green biomass yield across all harvests. The highest total green biomass yield (68469.67 kg ha<sup>-1</sup>) was recorded under the treatment F<sub>8</sub> (RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar spray of ZnSO<sub>4</sub> at 0.5 % at 40 and 80 DAS), followed by F<sub>6</sub> (61202.33 kg ha<sup>-1</sup>) and F<sub>7</sub> (59980.17 kg ha<sup>-1</sup>) (Table 1). These results indicate that the combined application of Zn through both soil and foliar routes significantly enhances biomass accumulation over sole RDF application (F<sub>1</sub>), which recorded the lowest total yield (43075.17 kg ha<sup>-1</sup>).

**Table 1.** Effect of Zn application on green biomass yield of multicut sorghum varieties

Treatment	Green biomass yield (kg ha <sup>-1</sup> )			
	1 <sup>st</sup> Harvest (60 DAS)	2 <sup>nd</sup> Harvest (100 DAS)	3 <sup>rd</sup> Harvest (130 DAS)	Total
Variety				
V <sub>1</sub> : SSG	23297.96	15901.67	7975.71	47175.33
V <sub>2</sub> : CSV 33MF	32861.17	19868.13	10885.88	63615.17
SEm (±)	588.22	580.11	367.57	1091.56
CD (5 %)	1698.90	1675.48	1061.63	3152.66
Zn fertilization				
F <sub>1</sub> : RDF	22571.17	13370.67	7133.33	43075.17
F <sub>2</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup>	27114.33	14935.00	7732.67	49782.00
F <sub>3</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS	29604.00	15633.00	8003.00	53240.00
F <sub>4</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 80 DAS	23491.83	17973.83	8593.00	50058.67
F <sub>5</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS and 80 DAS	29903.50	18481.17	8969.33	57354.00
F <sub>6</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS	32481.33	18659.17	10061.83	61202.33
F <sub>7</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 80 DAS	26513.50	21156.67	12310.00	59980.17
F <sub>8</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS and 80 DAS	32956.83	22869.67	12643.17	68469.67
SEm (±)	960.56	947.32	600.25	1782.51
CD (5 %)	2774.30	2736.05	1733.64	5148.27
Interaction	NS	NS	NS	NS

The significant improvement in green fodder yield with Zn fertilization can be ascribed to Zn's pivotal role in various physiological and biochemical processes, such as chlorophyll formation, auxin synthesis and enzyme activation, which are essential for vigorous growth and tiller development (5,17). Foliar application at critical growth stages further improves Zn availability and uptake, particularly under conditions where root uptake is constrained due to soil properties or moisture stress.

The increment in biomass with dual foliar applications (F<sub>5</sub>) and the integrated approach (F<sub>6</sub>, F<sub>7</sub>, F<sub>8</sub>) suggests that foliar supplementation effectively complements soil-applied Zn by addressing transient deficiencies during peak demand periods. This supports the findings of (18), who highlighted the efficiency of foliar nutrient application in enhancing dry matter yield in fodder crops.

#### Interaction effects

The interaction between varieties and Zn fertilization treatments was statistically non-significant for green biomass yield across all three harvests (Table 1). This suggests that while both factors independently influenced the yield, their combined effect did not significantly differ, indicating consistency in varietal performance across Zn application treatments.

#### Nutrient uptake

##### N uptake

Data presented in Table 2 indicate that CSV 33MF consistently showed significantly higher N uptake compared to SSG across all 3 harvests. In the 3<sup>rd</sup> cut, CSV 33MF recorded 24.06 kg ha<sup>-1</sup> N uptake compared to 21.37 kg ha<sup>-1</sup> in SSG. Among the Zn treatments, the maximum N uptake was observed with F<sub>8</sub> (RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar spray at 40 and 80 DAS), which recorded 43.27, 36.54 and 27.35 kg ha<sup>-1</sup> at the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> harvest, respectively. This was significantly superior to RDF alone (F<sub>1</sub>), indicating a substantial improvement in N assimilation with combined Zn applications.

The enhanced N uptake can be attributed to the role of Zn in promoting root development and enzyme activity related to N metabolism (5). Zn's involvement in auxin synthesis and chlorophyll production may have indirectly promoted better photosynthetic efficiency and root vigor, leading to improved nutrient absorption (19).

##### P uptake

Table 2 reveals a similar trend for P uptake, with CSV 33MF recording higher uptake than SSG. The combined application of Zn, especially F<sub>8</sub> (RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> +

**Table 2.** Effect of Zn application on nutrient uptake of multicut sorghum varieties

Treatment	N uptake (kg ha <sup>-1</sup> )			P uptake (kg ha <sup>-1</sup> )			K uptake (kg ha <sup>-1</sup> )			Zn uptake (g ha <sup>-1</sup> )		
	1 <sup>st</sup> Harvest (60 DAS)	2 <sup>nd</sup> Harvest (100 DAS)	3 <sup>rd</sup> Harvest (130 DAS)	1 <sup>st</sup> Harvest (60 DAS)	2 <sup>nd</sup> Harvest (100 DAS)	3 <sup>rd</sup> Harvest (130 DAS)	1 <sup>st</sup> Harvest (60 DAS)	2 <sup>nd</sup> Harvest (100 DAS)	3 <sup>rd</sup> Harvest (130 DAS)	1 <sup>st</sup> Harvest (60 DAS)	2 <sup>nd</sup> Harvest (100 DAS)	3 <sup>rd</sup> Harvest (130 DAS)
Variety												
V <sub>1</sub>	32.13	28.92	21.37	5.72	4.70	3.67	27.06	23.55	18.66	136.73	107.51	54.19
V <sub>2</sub>	35.66	32.89	24.06	6.44	5.38	4.13	34.81	26.63	20.91	156.00	119.40	60.44
SEm (±)	1.25	0.55	0.45	0.21	0.17	0.18	0.89	0.58	0.45	3.60	2.99	2.39
CD (5 %)	3.62	1.59	1.31	0.59	0.50	0.52	2.57	1.67	1.31	10.40	8.64	6.90
Zn fertilization												
F <sub>1</sub>	25.85	27.58	18.57	4.88	3.92	2.85	25.64	21.13	16.31	122.40	100.59	47.11
F <sub>2</sub>	31.00	28.00	20.35	5.44	3.92	2.90	29.34	21.68	17.61	139.60	101.39	48.18
F <sub>3</sub>	35.12	28.64	20.16	6.25	4.04	2.96	31.05	22.24	17.70	152.63	104.32	48.27
F <sub>4</sub>	26.28	29.69	22.28	5.00	4.62	3.75	25.68	24.37	19.22	122.61	111.85	57.59
F <sub>5</sub>	37.31	30.31	23.18	6.69	5.14	3.90	34.09	24.56	20.12	156.75	115.10	59.80
F <sub>6</sub>	41.69	32.15	24.40	7.40	5.40	4.51	36.10	27.01	21.36	164.36	118.43	60.05
F <sub>7</sub>	30.62	34.31	25.43	5.24	6.28	4.87	27.13	28.60	22.17	138.26	122.30	66.03
F <sub>8</sub>	43.27	36.54	27.35	7.73	7.00	5.42	38.46	31.13	23.82	174.35	133.69	71.51
SEm (±)	2.05	0.90	0.74	0.34	0.28	0.30	1.45	0.95	0.74	5.88	4.88	3.90
CD (5 %)	5.91	2.59	2.14	0.97	0.81	0.86	4.20	2.73	2.14	16.98	14.10	11.27
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

foliar spray at 40 and 80 DAS), recorded the highest P uptake (7.73, 7.00 and 5.42 kg ha<sup>-1</sup> in 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> harvest respectively). This may be due to Zn's role in enhancing P availability in soil and reducing P fixation (20). The foliar application may have also helped bypass soil-induced P deficiencies, enhancing plant uptake efficiency.

#### K uptake

K uptake (Table 2) also followed a similar pattern, with CSV 33MF showing superior uptake over SSG. Treatment F<sub>8</sub> (RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar spray at 40 and 80 DAS) once again recorded the highest K uptake across all harvests (38.46, 31.13 and 23.82 kg ha<sup>-1</sup>), significantly outperforming RDF (F<sub>1</sub>). K plays a critical role in stomatal regulation, enzyme activation and osmotic adjustment. Zn, by improving overall plant vigor and root surface area, may enhance K uptake efficiency (17).

#### Zn uptake

Zn uptake results further confirmed the positive impact of Zn fertilization, particularly when applied through both soil and foliar routes (Table 2). The maximum Zn uptake was again recorded in F<sub>8</sub>: RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar spray at 40 and 80 DAS (174.35, 133.69 and 71.51 g ha<sup>-1</sup>) at 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> harvest, highlighting the synergistic effect of dual application modes. CSV 33MF showed a significantly higher uptake of Zn than SSG, which may be linked to its superior root system and higher biomass productivity, leading to greater nutrient absorption.

This trend agrees with earlier findings which reported that foliar application of micronutrients at appropriate stages leads to better absorption and translocation in fodder crops (17,18).

#### Overall trends

Across all nutrients (N, P, K, Zn), both the variety and Zn fertilization treatments had significant effects, while their interactions were non-significant (Table 2). This indicates that the performance of varieties was consistent across Zn treatments. The superiority of CSV 33MF and F<sub>8</sub>(RDF + soil application at 20 kg ha<sup>-1</sup>+ foliar spray at 0.5 % at 40 and 80 DAS) treatment across all nutrients suggests a potential synergy between improved genetic potential and integrated micronutrient management.

These results corroborate previous findings that nutrient use efficiency in multicut sorghum can be optimized through integrated application of macronutrients and micronutrients,

especially Zn, which plays a key role in enzyme function and protein synthesis (16,21).

#### Effect of Zn application on crude protein content

The data presented in Table 3 reveal that both sorghum variety and Zn fertilization significantly influenced the crude protein content at all three harvests. Among the varieties, CSV 33MF consistently recorded higher crude protein percentages (4.99 %, 4.68 % and 4.45 % for the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> harvest respectively) compared to SSG (4.35 %, 4.55 % and 3.94 %). This significant varietal difference may be attributed to the higher N content in CSV 33 MF, which directly contributes to protein synthesis, as protein percentage is a function of N accumulation in plant tissues (22).

With respect to Zn fertilization, the treatment F<sub>8</sub>(RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar spray at 40 and 80 DAS) recorded the highest crude protein content across all harvests: 5.14 %, 5.00 % and 4.67 % respectively. This was significantly superior to the control (F<sub>1</sub>: RDF alone), which showed the lowest crude protein values (4.34 %, 4.34 % and 3.74 %). These findings suggest a clear benefit of integrated soil and foliar application of Zn in enhancing protein content in multicut sorghum.

The improvement in protein content with Zn application can be explained by Zn's pivotal role in several enzymatic reactions, including those involved in protein synthesis. Zn acts as a structural and catalytic component of ribosomes and plays an essential role in the synthesis of tryptophan and auxins, which regulate cell growth and division (5,23). Furthermore, improved N uptake observed under Zn treatments may have contributed to greater protein accumulation in plant tissues (Table 2) (16).

Additionally, foliar application of Zn at critical stages (especially 40 and 80 DAS) ensures immediate availability of Zn during peak nutrient demand, thereby improving metabolic functions and protein biosynthesis. Similar trends have been observed in previous findings, reported enhanced protein and forage quality in sorghum and other fodder crops with foliar micronutrient applications (18,21).

Overall, the results highlight that the combination of soil and foliar application of Zn is more effective in improving crude protein content than either method alone, likely due to better Zn bioavailability and continuous nutrient supply throughout the growth stages.

**Table 3.** Effect of zinc application on crude protein of multicut sorghum varieties

Treatment	Crude protein (%)		
	1 <sup>st</sup> Harvest (60 DAS)	2 <sup>nd</sup> Harvest (100 DAS)	3 <sup>rd</sup> Harvest (130 DAS)
<b>Variety</b>			
V <sub>1</sub> : SSG (Sorghum Sudan Grass)	4.35	4.55	3.94
V <sub>2</sub> : CSV 33MF	4.99	4.68	4.45
SEm (±)	0.05	0.05	0.05
CD (5 %)	0.14	0.14	0.16
<b>Zn fertilization</b>			
F <sub>1</sub> : RDF	4.34	4.34	3.74
F <sub>2</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup>	4.69	4.35	3.85
F <sub>3</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS	4.54	4.42	3.96
F <sub>4</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 80 DAS	4.39	4.60	4.25
F <sub>5</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS and 80 DAS	4.77	4.64	4.29
F <sub>6</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS	4.98	4.72	4.38
F <sub>7</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 80 DAS	4.49	4.88	4.43
F <sub>8</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS and 80 DAS	5.14	5.00	4.67
SEm (±)	0.08	0.08	0.09
CD (5 %)	0.23	0.22	0.25
Interaction	NS	NS	NS

## Effect of Zn application on the economics of multicut fodder sorghum

The data presented in Table 4 show that both the variety and Zn fertilization treatments significantly influenced the economic performance of multicut sorghum cultivation, as reflected in the cost of cultivation, gross returns, net returns and benefit-cost (B:C) ratio.

Among the 2 varieties evaluated, SSG exhibited superior economic performance with the highest net returns (₹44881 ha<sup>-1</sup>) and a B:C ratio of 1.73, despite having the lower cost of cultivation (₹25882 ha<sup>-1</sup>). In contrast, CSV 33MF incurred a much higher cost of cultivation (₹57082 ha<sup>-1</sup>) and returned a lower B:C ratio of 0.67, primarily due to higher seed cost and inputs without proportionate returns. This aligns with previous findings, reported that SSG varieties often outperform hybrids in terms of input-use efficiency under semi-arid conditions (24).

Regarding Zn fertilization, substantial differences were noted across treatments. The highest economic returns were recorded in F<sub>8</sub> (RDF + soil application of ZnSO<sub>4</sub> at 20 kg ha<sup>-1</sup> + foliar spray at 40 and 80 DAS), which achieved the maximum net return (₹59248 ha<sup>-1</sup>) and the highest B:C ratio of 1.36. This could be attributed to the synergistic effect of combined soil and foliar application of Zn, which significantly improved forage yield and quality, translating into better market returns (19,25).

The treatment F<sub>6</sub> (RDF + soil application + foliar spray at 40 DAS) also performed well economically (net return ₹49168 ha<sup>-1</sup>, B:C ratio 1.15), followed by F<sub>7</sub> and F<sub>5</sub>, indicating that foliar Zn application at either 40 or 80 DAS in combination with soil Zn significantly enhances profitability. Treatments with RDF alone (F<sub>1</sub>) showed the lowest net return (₹25105 ha<sup>-1</sup>) and B:C ratio (0.64), highlighting the importance of micronutrient management in sorghum systems (5).

The improved economics from Zn application can be attributed to enhanced plant metabolism, increased chlorophyll synthesis, improved nutrient uptake (especially N) and higher protein content in fodder - all contributing to increased yield and forage quality (18). Moreover, foliar application ensures quick nutrient availability during peak demand periods, thereby improving physiological efficiency and economic return per unit investment.

These results are consistent with earlier studies, observed that integrated Zn management significantly improved both yield attributes and farm profitability in fodder crops (21,26).

## Conclusion

The study clearly demonstrated that variety CSV 33MF significantly outperformed SSG in terms of biomass yield, nutrient uptake and crude protein content, although SSG was more economically viable due to its lower input cost. Zn fertilization, particularly the integrated approach combining soil application and foliar sprays (F<sub>8</sub>: RDF + soil application at 20 kg ha<sup>-1</sup> + foliar spray at 0.5 % at 40 and 80 DAS), markedly enhanced green biomass yield, nutrient assimilation (N, P, K, Zn) and crude protein content. This underlines the crucial role of Zn in promoting physiological efficiency and forage quality. However, economic analysis indicated that SSG with appropriate Zn application may offer better returns under resource-limited conditions. Overall, integrated Zn management proved to be an effective strategy for improving productivity and quality of multicut fodder sorghum.

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## Authors' contributions

SV carried out the field experiment, collection and analysis of data, VK participated in the sequence alignment and drafted the manuscript. MK participated in the design of the study, supervised the whole research and helped in compiling the manuscript. VB, AKB and MNS participated in the compilation of the manuscript. BS, HS, YK, VD and RM participated in the finalization of the manuscript. 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

**Table 4.** Effect of zinc application on relative economics of multicut sorghum varieties

Treatments	Cost of cultivation (₹ ha <sup>-1</sup> )	Gross returns (₹ ha <sup>-1</sup> )	Net returns (₹ ha <sup>-1</sup> )	B:C ratio
<b>Varieties</b>				
V <sub>1</sub> : SSG	25882	70763	44881	1.73
V <sub>2</sub> : CSV 33MF	57082	95423	38341	0.67
<b>Zn fertilization</b>				
F <sub>1</sub> : RDF	39507	64613	25105	0.64
F <sub>2</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup>	41815	74673	32858	0.79
F <sub>3</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS	40328	79860	39532	0.98
F <sub>4</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 80 DAS	40328	75088	34760	0.86
F <sub>5</sub> : RDF + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS and 80 DAS	41148	86031	44883	1.09
F <sub>6</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS	42636	91803	49168	1.15
F <sub>7</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 80 DAS	42636	89970	47334	1.11
F <sub>8</sub> : RDF + soil application of ZnSO <sub>4</sub> at 20 kg ha <sup>-1</sup> + foliar application of ZnSO <sub>4</sub> at 0.5 % at 40 DAS and 80 DAS	43456	102705	59248	1.36

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