



Research article

Optimizing seed rate and cutting stage of fodder sorghum (*Sorghum bicolor* (L.) Moench) for improved quality and yield

Nikhil, Maninder Kaur*, Simerjeet Kaur, Harpreet Kaur Oberoi and Sompal Singh

Punjab Agricultural University, Ludhiana-141004, India

*Corresponding author email: manindersindhu@pau.edu

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Abstract

An experiment was conducted at Ludhiana, India, during the rainy seasons of 2023 and 2024, in a randomized complete block design with three replications, to evaluate the impact of varying seeding rates (25, 37.5, 50, 62.5 and 75 kg/ha) and cutting stages (vegetative and flowering) on the nutritional quality and fodder productivity of sorghum. The results demonstrated a significant increase in green fodder yield with a higher seed rate up to 37.5 over 25 kg/ha. Beyond this level, yield improvement was marginal up to 62.5 kg/ha. A slight reduction in yield was observed at 75 kg/ha. Neutral detergent fiber, acid detergent fiber, and acid detergent lignin recorded a significant decrease, but *in-vitro* dry matter digestibility remained unaffected. However, ash content, crude protein and total soluble sugar were significantly high with seed rates of 50 to 62.5 kg/ha being at par with 37.5 kg/ha. Increasing the seeding rate significantly increased hydrocyanic acid content. Between the cutting stages, the flowering stage obtained a significant increase (10.8%) in green fodder yield with appreciable quality attributes over the vegetative stage. Thus, results indicate that production input of seed can be reduced without negative effects on the late maturing variety 'SL-46' of sorghum. Cutting at the flowering stage (80-85 DAS) is recommended to achieve higher yield and satisfactory nutritional quality.

Keywords: Cutting stage, Fodder, Nutritional quality, Seed rate, Sorghum, Yield

Introduction

Animal husbandry is a significant contributor to the Indian economy, with the livestock sector accounting for 30.2% of agricultural gross value added and 5.5% of the overall national economy (DAHD, 2025). It is a vital livelihood activity that supports agriculture, enhances nutrition, supplements income, generates employment, and serves as a reliable 'bank on hooves', functioning as a complementary enterprise. Ensuring the availability of nutritious fodder is vital for the viability and performance of dairy enterprises (Verma *et al.*, 2026).

Among the major *kharif* fodder crops, sorghum (*Sorghum bicolor* (L.) Moench) is the most suitable and widely cultivated crop due to its rapid growth, adaptability, and relatively high biomass yield, making it a key player in addressing fodder scarcity, especially during dry seasons (Iqbal *et al.*, 2015). Fodder sorghum has gained prominence as a drought-tolerant fodder crop suitable for diverse agro-climatic regions, especially in arid and semi-arid zones (Hossain *et al.*, 2022). It is nutritionally characterized by 8 to 10% crude protein, 60 to 65% neutral

detergent fiber, 37 to 42% acid detergent fiber, about 32% cellulose and 21 to 23% hemi-cellulose, indicating its suitability as a livestock feed (Kumar *et al.*, 2025). Maximizing the productivity and nutritive quality of forage sorghum, particularly in newly released varieties, requires strategic agronomic management. Although nutritional quality is primarily governed by genetic traits, it can be significantly enhanced through key practices such as optimization of seed rate and harvesting stage (Kumar *et al.*, 2018).

Seed rates directly influence plant population density, which in turn affects intra-specific competition, light interception, tillering behavior, and ultimately, biomass accumulation and nutritive value. Adoption of an optimum seed rate suited to specific agro-climatic conditions enhances both productivity and forage quality (Kumar *et al.*, 2016). An optimum seed rate ensures adequate plant stand and maximizes the utilization of available resources such as water, nutrients and light. Therefore, optimizing seed rate is crucial to achieve an optimal balance of yield and quality.

Similarly, the stage of cutting significantly affects the nutritional quality of forage sorghum. As the plant matures, there is a progressive increase in dry matter yield due to increased structural development, but this is often accompanied by a decline in nutritive traits such as crude protein content, digestibility, and palatability (Khalilian *et al.*, 2022). Early harvest stages tend to have higher crude protein and lower fiber content, making them more digestible and beneficial for animal performance, particularly for young and lactating animals. Conversely, late harvest stages, while yielding more biomass, are often less nutritious due to lignification and increased fiber content. With the background of development and release of new late maturing and high biomass breeding lines recommended for cultivation, the present study was undertaken to investigate the effects of varying seed rates and different cutting stages on the nutritive quality and forage yield of the single-cut sorghum variety 'SL-46'. The findings are expected to offer practical recommendations for better forage management practices, ultimately enhancing animal performance and supporting sustainable livestock production systems.

Materials and Methods

Study site and experimental design: The field experiment was conducted during the rainy (*kharif*) seasons of 2023 and 2024 at the Forage Research Farm, Punjab Agricultural University, Ludhiana (30°54' N, 75°48' E; 247 m above mean sea level), located in the central plains of Punjab within the Trans-Gangetic agro-climatic zone of India. The region is characterized by a subtropical climate with hot and humid conditions during the *kharif* season. The experimental soil (0-30 cm depth) was loamy sand in texture, slightly alkaline (pH 8.3), with an electrical conductivity of 0.13 dS/m (1:2 soil-water suspension). It was low in organic carbon (3.52 g/kg) and available nitrogen (164.8 kg/ha), while medium in available phosphorus (18.97 kg/ha) and potassium (143.12 kg/ha). The mean annual rainfall of the site is 759 mm, with 391.4 mm and 519.1 mm received during the crop growth periods of 2023 and 2024, respectively.

The field was tilled twice using a disc harrow to incorporate the stubble of the previously grown crop, followed by two ploughings with a tractor-drawn cultivator. Each plowing was followed by planking to achieve a fine seedbed preparation. The crop was sown on 11 June 2023 and 13 June 2024 using the *kera* method with a row spacing of 25 cm. A basal dose of 50 kg N/ha (equivalent to 108 kg urea) and 20 kg P₂O₅/ha (125 kg single superphosphate) was applied at sowing, followed by top-dressing of 50 kg N/ha at 30 days after sowing, as per the recommendations of Punjab Agricultural University. The experiment was laid out in a randomized

complete block design with five levels of seed rate (25, 37.5, 50, 62.5 and 75 kg/ha) and two cutting stages (vegetative stage-65 DAS and flowering stage-85 DAS). Each experimental unit consisted of 4 × 3 m plot. Management practices were adopted as per the recommendations of the sorghum crop for the region.

Laboratory analysis: The crop was harvested manually as per treatment. Fresh fodder yield was recorded and samples were collected periodically at 30, 50 DAS and at both cutting stages (Harvest) and subjected to laboratory analysis for different quality parameters. Plant samples collected were dried in a hot air oven at 60 ± 5°C till constant weight was attained. Thereafter, oven-dried samples were ground to pass through 40 mesh sieves in a Macro-Wiley Mill and used for chemical analysis. Quality (proximate) analysis was performed using the standard methods on all samples collected. The nitrogen content in the sample was determined using the Macro-Kjeldahl method (AOAC, 1990). Crude protein was calculated by multiplying nitrogen content by 6.25. Methods proposed by Van Soest *et al.* (1991) were used to calculate the relative amounts of cell wall components like neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL). Total ash content was evaluated by standard methods by AOAC (1990). *In-vitro* dry matter digestibility was analyzed according to Tilley and Terry (1963). The HCN content was determined using the picric acid method described by Hogg and Ahlgren (1942). Total soluble sugar (TSS) content was measured using a portable refractometer.

Statistical analysis: The data obtained from the two years' study (2023 and 2024) were pooled for all the parameters studied and were analyzed with the help of the analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for a randomized complete block design using OPSTAT. The least significant test was used to decipher the main and interaction effects of treatments at 5% level of significance ($p < 0.05$). Graphs were prepared using MS-Excel.

Results and Discussion

Green fodder yield: Green fodder yield of sorghum was significantly influenced by seeding rate and cutting stage in both years of the study (Fig 1). Among the seeding rates, 62.5 kg/ha achieved the highest green fodder yield, which is statistically comparable to 37.5, 50, and 75 kg/ha seed rates. Yields slightly declined at the highest seeding rate of 75 kg/ha, while the lowest yield was observed at 25 kg/ha. The observed yield response was attributed to the attainment of optimum plant height, improved stem girth, adequate plant population, and enhanced dry matter accumulation. In contrast, a slight decline

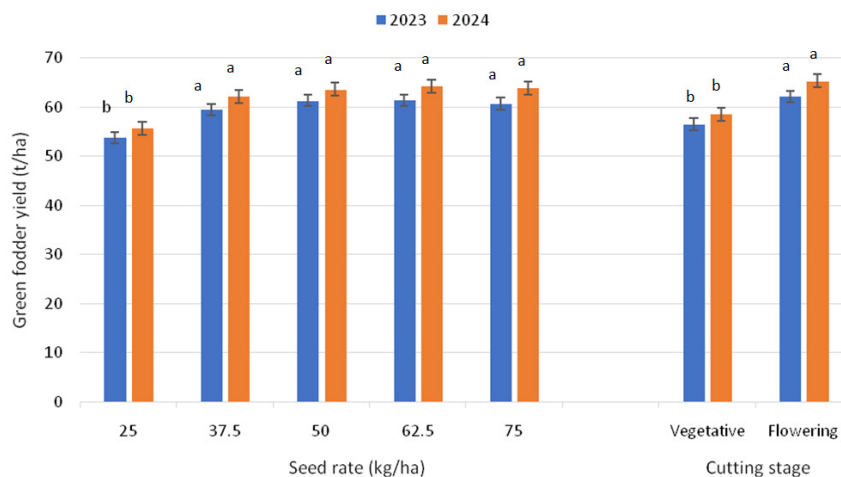


Fig 1. Green fodder yield of sorghum as influenced by seed rate and cutting stage. Different letters on bars indicates significant difference ($P < 0.05$)

in green fodder yield at the highest seed rate (75 kg/ha) may be ascribed to excessive plant density, leading to intensified competition for light and nutrients, resulting in reduced stem thickness and increased plant elongation, ultimately lowering yield, as also reported by Nabooji *et al.* (2018) and Somashekar *et al.* (2018). The lowest yield recorded at 25 kg/ha can be attributed to sub-optimal plant population. Additionally, the cutting stage had a significant effect on green fodder yield, with harvest at the flowering stage consistently producing higher yields than at the vegetative stage. This increase is likely attributable to greater biomass accumulation at later growth stages, corroborating the findings of Chattha *et al.* (2017) and Kadam *et al.* (2019).

Crude protein: The crude protein (CP) content of sorghum was significantly influenced by both seeding rate and cutting stage, particularly at 50 DAS and at the harvest stage (Table 1). At the earlier growth stage (30 DAS), CP content remained statistically similar across all seeding rates and cutting stages. Whereas, at 50 DAS, the highest CP content (9.65%) was obtained at a seeding rate of 37.5 kg/ha, which was statistically comparable to a 50 kg/ha seed rate. These findings indicate that moderate seeding rates tend to favor higher protein accumulation. However, at the harvest stage, seeding rate effects became more pronounced. The 37.5 kg/ha seeding rate recorded the highest CP content (8.29%), statistically at par with 50 kg/ha. In contrast, both lower (25 kg/ha) and higher seeding rates (75 kg/ha) produced significantly lower CP content. This trend suggests that moderate plant populations may optimize nutrient uptake and metabolic activity, enhancing protein synthesis, while excessively low or high seeding densities may limit CP accumulation due to suboptimal resource utilization or increased intra-specific competition. These results are consistent with the findings of Aslam *et al.* (2011), who

reported improved forage quality at moderate planting densities.

The cutting stage also had a significant effect on CP content. Harvesting at the vegetative stage (8.05%) produced significantly higher CP values than the flowering stage (7.22%). The observed decline in CP content with advancing plant maturity can be attributed to physiological changes during development. During the transition from vegetative to reproductive stages in sorghum, nitrogenous compounds, including proteins, are increasingly translocated to reproductive structures. Simultaneously, the accumulation of structural carbohydrates such as cellulose, hemicellulose, and lignin leads to a dilution effect, reducing the relative protein concentration. These observations corroborate earlier findings by Shahid (2012), Swathi *et al.* (2016) and Chattha *et al.* (2017) who reported similar trends in protein decline with advancing maturity.

Neutral detergent fiber: The neutral detergent fiber (NDF) content of sorghum, which encompasses hemicellulose, cellulose, and lignin, was influenced significantly by seeding rate and cutting stage, particularly at the harvest stage (Table 1). No significant differences in NDF content were observed across treatments at 30 and 50 DAS, indicating that early vegetative growth stages may not substantially affect fiber accumulation.

At the harvest stage, the highest NDF content (68.93%) was recorded at the lowest seeding rate of 25 kg/ha, which was statistically at par with 37.5 kg/ha (65.86%). A notable reduction in NDF content was observed at 50 kg/ha (63.57%), and further reductions were recorded at 62.5 and 75 kg/ha (63.67 and 63.05%, respectively), though these values were statistically similar. These findings suggest that reduced plant density encourages the development of thicker stems, promoting the

Table 1. Crude protein, NDF and ADF content of sorghum at different growth stage as influenced by seed rate and cutting stage (pooled data of two years)

Treatments	Crude protein (%)			Neutral detergent fibre (%)			Acid detergent fibre (%)		
	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest
Seeding rate (kg/ha)									
25	9.68	8.80	7.50	56.34	61.18	68.93	30.10	34.12	40.23
37.5	9.10	9.65	8.29	56.03	61.13	65.86	29.42	35.15	39.72
50	9.09	9.44	8.04	55.73	59.28	63.57	30.52	33.52	38.20
62.5	9.07	8.48	7.50	55.28	60.15	63.67	30.33	32.90	37.23
75	9.08	8.43	6.85	55.87	61.28	63.05	30.05	32.67	36.72
CD (P<0.05)	NS	0.76	0.37	NS	NS	4.06	NS	NS	2.24
Cutting stage									
Vegetative	9.13	8.99	8.05	55.80	60.45	63.02	30.37	33.96	37.16
Flowering	9.28	8.94	7.22	55.91	60.76	67.01	29.80	33.38	39.67
CD (P<0.05)	NS	NS	0.23	NS	NS	2.57	NS	NS	1.42

Table 2. Acid detergent lignin, ash and HCN content of sorghum at different growth stage as influenced by seed rate and cutting stage (pooled data of two years)

Treatments	Acid detergent lignin (%)			Ash content (%)			HCN content (ppm)		
	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest
Seeding rate (kg/ha)									
25	5.85	7.68	9.40	5.64	6.37	8.88	58.12	43.05	20.06
37.5	5.87	7.33	9.27	5.60	6.66	9.61	60.47	46.65	18.42
50	6.48	7.30	9.82	5.28	6.76	9.91	62.35	49.83	20.83
62.5	5.78	6.44	8.82	5.47	6.83	8.02	65.56	50.12	24.58
75	5.42	6.28	8.05	5.11	5.35	7.58	69.21	49.41	30.17
CD (P<0.05)	NS	NS	0.61	NS	0.76	1.31	3.33	NS	1.90
Cutting stage									
Vegetative	5.84	7.08	8.23	5.32	6.39	8.27	62.88	47.75	28.23
Flowering	5.92	6.93	9.91	5.51	6.39	9.32	63.40	47.88	17.40
CD (P<0.05)	NS	NS	0.39	NS	NS	0.83	NS	NS	1.20

accumulation of structural carbohydrates and resulting in higher fiber content. This inverse relationship between seeding rate and NDF content aligns with previous studies by Sher *et al.* (2017) and Mekasha *et al.* (2022), which attribute increased fiber accumulation in sparsely planted stands to enhanced stalk development and lignification. Conversely, denser stands may suppress individual plant growth and limit the deposition of structural materials. However, these results are not consistent with findings by Kumar *et al.* (2017), who reported an opposite trend.

The cutting stage also had a significant effect on NDF content. The flowering stage exhibited markedly higher NDF concentrations than the vegetative stage. NDF

content increased from 63.02% at the vegetative stage to 67.01% at flowering. This increase is likely due to greater synthesis of structural carbohydrates and enhanced lignification during plant maturation. These findings are in agreement with those of Sher *et al.* (2017) and Salama *et al.* (2019a), who reported increased fiber fractions at advanced growth stages. However, they are in contrast to the observations of Atis *et al.* (2012), who documented a decline in fiber content with delayed harvesting.

Acid detergent fiber: Acid detergent fiber (ADF), comprising mainly cellulose and lignin, is a critical determinant of forage digestibility. In the present study, ADF content of sorghum was significantly influenced

Table 3. IVDMD and total soluble sugar content of sorghum at harvest as influenced by seed rate and cutting stage

Treatments	IVDMD (%)		Total soluble sugar (%)	
	2023	2024	2023	2024
Seeding rate (kg/ha)				
25	39.6	38.3	8.0	7.8
37.5	41.3	41.0	9.0	9.8
50	42.2	41.7	9.8	9.2
62.5	40.4	41.8	8.6	8.7
75	41.2	42.1	7.7	7.9
CD (P<0.05)	NS	NS	NS	1.2
Cutting stage				
Vegetative	43.0	42.9	6.2	6.2
Flowering	38.9	39.1	11.0	11.2
CD (P<0.05)	2.7	3.4	1.0	0.8

by seeding rate and cutting stage at the harvest stage, while no significant differences were detected at 30 and 50 DAS (Table 1). The highest ADF content (40.23%) was observed at the lowest seeding rate of 25 kg/ha, which was statistically at par with 37.5 kg/ha (39.72%) and 50 kg/ha (38.20%). This trend indicates that lower plant densities promote better stalk development and increased stem thickness, facilitating the accumulation of structural carbohydrates such as cellulose and lignin; a finding consistent with Xue *et al.* (2016), who reported a decline in water-soluble carbohydrates, cellulose and lignin contents of the third internode with increasing plant density.

The cutting stage significantly influenced ADF content at the harvest stage. The flowering stage exhibited an ADF content of 39.67%, significantly higher than 37.16% recorded at the vegetative stage. This consistent increase in ADF with delayed harvest is likely a consequence of greater synthesis of structural carbohydrates and progressive lignification as the plant matures.

Acid detergent lignin: ADL is the most indigestible fraction of plant cell walls, primarily composed of lignin and residual cellulose. In the present study, ADL content of sorghum was significantly influenced by both seeding rate and cutting stage at the harvest stage, while no significant differences were recorded at 30 and 50 DAS (Table 2). The highest ADL content (9.82%) was observed at the seed rate of 50 kg/ha, which was statistically at par with 37.5 kg/ha (9.27%) and 25 kg/ha (9.40%). A marked reduction in ADL was recorded at higher seeding rates, with the lowest value of 8.05% noted at 75 kg/ha. These findings suggest that lower plant densities promote the development of thicker and more lignified stalks, contributing to increased ADL content. The cutting stage

had a pronounced effect on ADL content. The flowering stage recorded significantly higher ADL values than the vegetative stage. ADL content increased from 8.23% at the vegetative stage to 9.91% at flowering. This trend reflects increased lignification as the plant progresses toward maturity, leading to greater deposition of indigestible structural components. Similar findings were reported by Sher *et al.* (2017) and Salama (2019a) who documented a steady rise in lignin content with delayed harvest.

Ash content: It represents the total mineral content in forage, hence is an important parameter influencing the nutritive value of fodder. Ash content was significantly affected by seeding rate and cutting stage, particularly at 50 DAS and at the harvest stage, while no significant differences were observed at 30 DAS (Table 2). At 50 DAS, the highest ash content (6.83%) was recorded at a seeding rate of 62.5 kg/ha, statistically at par with 25 kg/ha (6.37%), 37.5 kg/ha (6.66%) and 50 kg/ha (6.76%), while the lowest was observed at 75 kg/ha (5.35%).

At the harvest stage, seeding rate continued to exert a significant influence. The highest ash content was recorded at 50 kg/ha (9.91%), statistically at par with 25 and 37.5 kg/ha, while the lowest values were consistently observed at the highest seeding rate of 75 kg/ha (7.58%). These results suggest that moderate seeding rates may promote optimal nutrient uptake and accumulation, whereas dense plant stands may experience nutrient competition, reducing mineral content. These results were in contrast with the findings of Sher *et al.* (2016).

The cutting stage also significantly influenced ash content at the harvest stage. The ash content was significantly higher at the flowering stage compared to the vegetative stage. The flowering stage recorded 9.32%, while the vegetative stage recorded 8.27%. The increase in ash content at the flowering stage may be due to prolonged nutrient translocation and mineral accumulation in plant tissues as the crop matures. Similar trends have been reported by Sher *et al.* (2016), Chatta *et al.* (2017) and Kadam *et al.* (2019), where later developmental stages in forage crops show increased ash content due to mineral deposition in structural tissues. The results obtained in this study contradict the findings of Shahid (2012) and Salama (2019b).

Hydrogen cyanide: HCN content is a crucial factor in evaluating the safety of sorghum as a fodder crop, since excessive HCN levels can be toxic to livestock. The results revealed that the seeding rate significantly affects HCN content at 30 DAS and at the harvest stage (Table 2). At 30 DAS, the highest HCN content (69.21 ppm) was observed at the 75 kg/ha seeding rate, while the lowest (58.12 ppm) was recorded at 25 kg/ha. Similarly, at harvest, the highest HCN levels were again recorded with 75 kg/ha (30.17 ppm), whereas 37.5 kg/ha had the lowest HCN

values (18.42 ppm). These findings suggest that denser plant stands may induce stress, potentially increasing cyanogenic glycoside accumulation.

The cutting stage significantly influenced HCN content at the harvest stage, with the vegetative stage recording higher HCN concentrations (28.23 ppm) than the flowering stage (17.40 ppm). This trend reflects the natural decline in cyanogenic compounds as the plant matures, which is consistent with findings of Sher *et al.* (2012), who reported that HCN levels are highest during early growth and diminish as sorghum matures. According to Pandey *et al.* (2011), HCN levels in forage crops typically decline to non-toxic levels by 45 to 50 days after planting.

In-vitro dry matter digestibility: IVDMD is a key parameter for evaluating the nutritive quality of fodder, as it represents the proportion of dry matter that is digestible by livestock. In the present study, IVDMD was assessed at the harvest stage to determine the effects of seeding rate and cutting stage on forage quality (Table 3). The results indicated that seeding rate had no significant influence on IVDMD in either 2023 or 2024, as reflected by the non-significant differences across treatments. Although numerically higher IVDMD values were observed at moderate to higher seeding rates (50 and 75 kg/ha), these differences did not reach statistical significance. The trend of increased digestibility at higher seeding rates may be associated with reduced stem thickness and lower accumulation of fiber components (NDF, ADF and ADL), as previously reported by Mekasha *et al.* (2022). However, the lack of statistical significance suggests that seeding rate alone may not be a strong determinant of IVDMD under the conditions of this study.

In contrast, the cutting stage significantly influenced IVDMD in both years. The vegetative stage consistently exhibited higher digestibility, with IVDMD values of 43.0% in 2023 and 42.9% in 2024, compared to 38.9 and 39.1% recorded at the flowering stage, respectively. The decline in digestibility with advancing plant maturity is attributed to increased lignification and the greater accumulation of indigestible structural carbohydrates in the cell walls, which limit rumen microbial fermentation. A similar pattern was observed by Salama (2019b).

Total soluble sugar: Total soluble sugar content is a vital parameter in evaluating the energy value of fodder, as it directly influences both its palatability and digestibility for livestock. The results indicated that seeding rate significantly affected total soluble sugar content at the harvest stage in 2024, but not in 2023 (Table 3). In 2024, the highest sugar content (9.8%) was observed at the 37.5 kg/ha seeding rate, which was statistically at par with 50 and 62.5 kg/ha. In contrast, the lowest sugar content (7.9%) was recorded at the highest seeding rate of 75 kg/ha, suggesting that moderate seeding rates optimize sugar accumulation, likely due to better resource availability

and reduced inter-plant competition. These findings are consistent with the idea that dense planting can limit carbohydrate synthesis and accumulation due to stress and nutrient competition.

The cutting stage had a highly significant impact on total soluble sugar content at harvest during both years. The flowering stage recorded substantially higher sugar levels (11.0% in 2023 and 11.2% in 2024) compared to the vegetative stage (6.2% in both years). This pronounced increase in sugar content during the flowering stage can be attributed to active translocation and accumulation of soluble carbohydrates as the plant reaches physiological maturity. The metabolic shift toward reproductive development promotes the storage of sugars in stems and leaves, thereby increasing their concentration in the forage. Chattha *et al.* (2017) also reported a similar increase in sugar content with plant age and maturity.

Conclusion

The results demonstrated that cultivation of improved forage sorghum varieties gives a substantial jump in fodder yields and quality that is hugely beneficial for marginal and small farmers to fulfill their requirements of green fodder for their livestock. The full potential of these varieties in terms of their yield and quality is possible through the use of an optimum seed rate, as well as their harvesting at the right stage. The two-year study recommends sowing the newly released sorghum variety (SL-46) at a seed rate of 37.5 to 50 kg/ha to achieve higher green fodder yield and better nutritional quality. The crop should be harvested at 80 to 85 days after sowing, which corresponds to the flowering stage, to achieve higher yield and highly acceptable nutritional quality. By bridging the gap between fodder demand and supply, these findings contribute to the sustainability and resilience of India's livestock sector, ensuring its continued role in supporting rural livelihoods and national food security.

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