Indian Journal of Agricultural Sciences **96** (1): 063–069, January 2026/Article
https://doi.org/10.56093/ijas.v96i1.165132

Assessment of different sowing windows and crop geometry on fodder yield, quality and economics of dual-purpose sorghum (*Sorghum bicolor*)

YERRADODDI SINDHU SREE[1], R KARTHIKEYAN[1]*, K BOOMIRAJ[1], M DJANAGUIRAMAN[1], M THIRUNAVUKKARASU[1], R AROCKIA INFANT PAUL[1], N JEEVAN[1] and JAKKU PRASANNA[1]

Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003 India

Received: 20 February 2025; Accepted: 01 December 2025

ABSTRACT

Sorghum [*Sorghum bicolor* (L.) Moench] is inherently drought-tolerant, however, escalating climate variability, intensifying environmental stresses, and widening fodder shortages underscore the critical need to refine sowing time and crop geometry to enhance productivity. Therefore, field experiments were conducted during summer and rainy (*kharif*) 2022 and winter (*rabi*) 2022–2023 seasons at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to evaluate the effect of sowing window and crop geometry on yield and quality of dual-purpose sorghum (grain + fodder). The experiment was laid out in strip plot design (SPD) with three replications. Treatments included date of sowing as Factor I, i.e. First fortnight (I FN) of February, March and April months during summer 2022 season, I FN of May, June, July months during *kharif* 2022 season and II FN of August, September and October during *rabi* 2022–2023 season and six different crop geometries as Factor II, viz. 45 cm × 15 cm (S_1); 45 cm × 10 cm (S_2); 45 cm × 5 cm (S_3); 30 cm ×15 cm (S_4); 30 cm × 10 cm (S_5) and 30 cm × 5 cm (S_6). Results revealed that the crop sown in I FN of April with spacing of 30 cm × 5 cm recorded significantly the highest green fodder yield (35.5 t/ha) with low crude fibre, high total digestible nutrients (TDN). The study affirmed clear shift in yield and quality across multiple seasons and helps farmers in selecting the most productive planting time and crop geometry across seasons. The benefit-cost ratio was highest (2.63) when sowing was taken during April I FN along with 30 cm × 5 cm spacing compared to all other sowing windows in respective seasons.

Keywords: Crop geometry, Crude protein, Dual-purpose sorghum, Green fodder, Quality, Sowing window, Yield

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the major cereal crops grown in India. It is widely cultivated as a forage crop, serving as its main source of fodder to meet the green and dry fodder needs of dairy animals. It is a short-day plant, and its response to photoperiod and temperatures varies, allowing it to adapt to a wide range of environments (Upadhyaya *et al.* 2021, Sree *et al.* 2023). Considering the impact of climate change, sowing time and cultivar choice can significantly affect sorghum productivity. In regions with limited cumulative temperature, the sowing window is very narrow due to lower accumulation of growing degree days, and the sowing date plays a key role in seedling emergence and successful establishment. Similarly, in areas with limited rainfall, selecting the right sowing date determines how efficiently the crop utilises rainfall. Therefore, choosing the optimal sowing date is important, as well as selecting the right variety and nutrition, since all these factors contribute to increased production (Ajaj *et al.* 2021). Planting within the optimal sowing window, considering the maturity length of cultivars, is crucial for maximizing crop yields (Akinseye *et al.* 2023).

In Tamil Nadu, sorghum is cultivated in an area of 4.01 lakh hectares with a productivity of 612 kg/ha mainly as rainfed crop during monsoon season and with residual moisture during *rabi* season. Most of the farmers practice broadcasting method without maintaining plant population for fodder production, leads to fodder shortages during the off period. The number of plants per unit area is a crucial factor for maximizing biomass production and ensuring high-quality crop and fodder. It is essential to strike a balance between the plant density and competition, as excessive competition can hinder overall crop efficiency, while low plant density may fail to fully utilise production potential (Umesh *et al.* 2022). Climate variability, particularly fluctuations in temperature and rainfall, significantly alters the nutritional composition of sorghum (Prasad *et al.* 2021). Evidence presented by Widodo *et al.* (2025) indicate a decrease in TDN from 61–44% and increase in Acid Detergent Fibre (ADF) to as high as 37% due to climatic stress. So, quality plays a major role in fodder palatability by animal.

[1]Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. *Corresponding author email: agrikarthi@yahoo.co.in

Keeping all this in view, present research was emphasized on both rainfed and irrigated conditions to optimise the spacing and sowing dates, ensuring consistent availability of quality fodder throughout all seasons. Additionally, it aimed to improve the quality and palatability of the fodder for livestock and enable longer storage. Furthermore, this research seeks to predict the impact of climate change on sorghum production.

MATERIALS AND METHODS

The field experiments were conducted in three seasons i.e. summer and rainy (*kharif*) 2022 and winter (*rabi*) 2022–2023 seasons at Tamil Nadu Agricultural University, Coimbatore (11º N, 76 º E; at an elevation of 426. 4 m amsl), Tamil Nadu. The experiment site receives a mean annual rainfall of 715 mm in 45 rainy days of which 49% is received during the north-east monsoon season (October–December). The soil of experimental field is sandy clay loam in texture with a *p*H of 8.2. Initial soil status was found to be medium in organic carbon (0.52%), low in available nitrogen (221 kg/ha), medium in available phosphorus (16.9 kg/ha), and high in available potassium (627 kg/ha). Sorghum CO-32 variety chosen for the study which was released from Tamil Nadu Agricultural University, Tamil Nadu. Its duration ranges from 105–110 days with dry fodder yield of 11.7 t/ha and 6.50 t/ha under irrigated and rainfed conditions, respectively.

The experiment was laid out in a strip plot design (SPD) with sowing window as horizontal strip and crop geometry as vertical strip which was randomized within the horizontal strip and replicated thrice and the size of the plot was 4.5 m × 3 m. The treatment details were represented in Table 1. Summer and *kharif* crops are grown as irrigated while *rabi* as rainfed crop with life-saving irrigation on the third day of sowing. The recommended fertiliser dose of 90:45:45 kg N, P_2O_5, and K_2O/ha was followed. Whereas for rainfed sorghum, the recommended dose of 40:20 kg N and P_2O_5/ha was applied.

Daily meteorological data for crop growing seasons were obtained from the Agro-Climate Research Center's Agromet observatory in Coimbatore. This data were converted into Standard Meteorological Weeks (SMW) (Fig. 1). During summer, the mean minimum and maximum temperatures were 23.4°C and 33.2°C, respectively. In

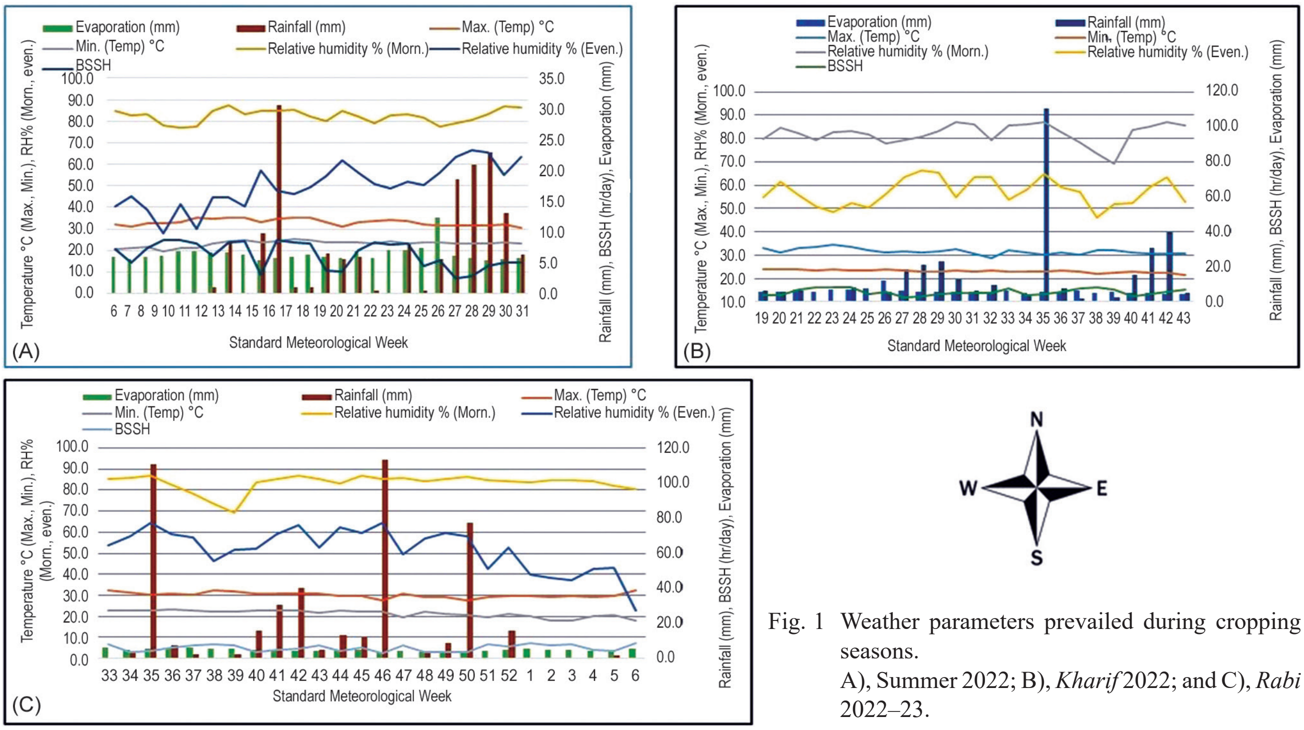

Fig. 1 Weather parameters prevailed during cropping seasons. A), Summer 2022; B), *Kharif* 2022; and C), *Rabi* 2022–23.

Table 1 Treatment details

Sowing window	Irrigated		Sowing window	Rainfed	Crop geometry
	Summer (2022)	*Kharif* (2022)		*Rabi* (2022–23)	
D_1, I FN	February	May	D_1, II FN	August	S_1, 45 cm × 15 cm
					S_2, 45 cm × 10 cm
D_2, I FN	March	June	D_2, II FN	September	S_3, 45 cm × 5 cm
					S_4, 30 cm × 15 cm
D_3, I FN	April	July	D_3, II FN	October	S_5, 30 cm × 10 cm
					S_6, 30 cm × 5 cm

FN, Fortnight

kharif, the mean minimum and maximum temperatures were 23.1°C and 31.3°C, while in *rabi,* they were 21.4°C and 30.1°C, respectively.

For recording stem girth, the thickness of the basal portion of the stem, preferably between third and fourth node from the base of each selected plant was measured at the time of harvest with the help of thread and recorded in centimetre (cm). The crop was harvested at 50 per cent flowering stage for accounting fodder yield. The sorghum fodder in 1 m^2 area of each net plot was cut close to the ground level and the fresh weight was recorded and the value was expressed in kg/ha. As recommended by Humphries (1956), the total nitrogen content of green fodder was calculated using the micro Kjeldahl's method. The crude protein content of each treatment was then calculated and expressed as a percentage by multiplying the result by 6.25. The crude fibre content of green fodder was determined gravimetrically by successively digesting and washing a weighted portion of the plant sample with diluted acid and alkali (Goering and Van Soest 1970, Altman *et al.* 2022). Crude fibre was the amount of material that remained undigested and was reported as a percentage.

Total digestible nutrients (TDN) were determined using the formula as suggested by Redfearn *et al.* (2004) and was expressed in percentage in green fodder.

$$TDN \% = 96.35-(1.15 \times ADF \%) \text{ or } 87.84-(ADF \% \times 0.7)$$

The experimental data were subjected to two-way analysis of variance (ANOVA) appropriate for strip-plot design (SPD) using the method described by Gomez and Gomez (1984) and the standard error of the mean (SEM±) and the least significant difference (LSD) at the 5% significance level were calculated for each treatment to enable statistical comparison of treatment means.

RESULTS AND DISCUSSION

Green fodder yield: The adaptation of different sowing windows and crop geometries significantly influenced the green fodder yield of dual purpose sorghum during all the seasons, since optimum time of sowing ensures desired growth of plant which ultimately determines the yield (Table 2). During summer season, significantly higher green fodder yield was observed when sowing was taken on I FN of April with a yield of 35.5 t/ha compared with other sowing windows. This could be due to prevalence of maximum temperatures within a favourable range of 28–34ºC during major part of crop duration which helped in boosting the crop growth. Similar trends observed by Ammaiyappan *et al.* (2025) indicated exploitation of favourable climatic conditions by the plants at the important growth stages and higher LAI in April sowing might have contributed to more dry matter production by enhancing the photosynthetic rate. In *kharif* sown crop, higher green fodder yield was registered with I FN of June sowing with a mean yield of 27.4 t/ha followed by I FN of July sowing. Whereas, II FN of September registered higher green fodder yield (22.8 t/ha) during *rabi* season. This is associated with improved soil moisture availability throughout the growing period, likely due to optimum temperature and rainfall during the growing period leading to better growth parameters and ultimately yield during respective sowing windows. These are consistent with findings of Agele *et al.* (2025) who reported that early sowing during June and July in semiarid regions enhanced biomass production due to ambient temperature, humidity, higher growing degree days, longer length of growing season (122 days) offered abundant opportunity for resource capture for vegetative growth (longer days to flowering). Mahalle *et al.* (2022) found that higher green and dry forage yields with 7th June sowing [24th Meteorological Week (MW)] compared to later sowing dates 25th (24 June) and 27th MW (7 July). Early sowing of sorghum significantly enhances growth rates and fodder yields by providing favourable temperature and light conditions, which boost photosynthesis and plant development (Ahmad *et al.* 2025).

Regarding the influence of plant spacing on green fodder yield, closer spacing (30 cm × 5 cm) registered significantly higher fodder yield compared to wider spacing of 45 cm × 15 cm during all three seasons. This is because narrow spacing leads to a higher leaf area index, which is associated with more leaves available to intercept sunlight, thereby increasing crop productivity. Studies show that sorghum's vegetative growth parameters, including plant height and leaf size, are positively influenced under narrow planting (Baghdadi *et al.* 2012, Herrera *et al.* 2024).

Yield and weather parameters were correlated, scatterplots with fitted linear regression lines were used to visualise the association between yield and major weather parameters (Fig. 2) and the results revealed that there exists a positive correlation (p<0.01) with T_{max} (r=0.87), T_{min} (r=0.80), and growing degree days (r=0.98). This means that an increase in mean T_{max} and T_{min} of the crop growing period increases fodder yield. Yield showed a negative linear relation with rainfall (r=-0.71), moderate negative with relative humidity morning (r=-0.52), and weakly negative with relative humidity evening (r=-0.23). This could be primarily due to reduced solar radiation, lower vapour pressure deficit, decreased photosynthetic efficiency and waterlogging, high incidence of pests (Kim and Sung 2023).

Quality parameters: Sowing window and crop geometry significantly influenced crude protein (CP), crude fibre (CF) content and total digestible nutrients (TDN) during all the three seasons (Table 3). During summer season, higher crude protein content (7.15%), total digestible nutrients (63%) and lowest crude fibre (27.96%) content was observed when crop was sown during I FN of April. In *kharif* season, higher CP content of 6.62%, the lowest CF of 28.49% and highest TDN value of 61.73% in green fodder were recorded in June I FN sown crop. During *rabi* 2022–23 season, sowing during II FN of September and II FN of August sowing were statistically comparable in recording the CP content of 5.63 and 3.96%, respectively in green fodder. Higher TDN of 59.44% and lowest CF content (29.28%) were registered in II FN of September sowing. Moderate temperature during

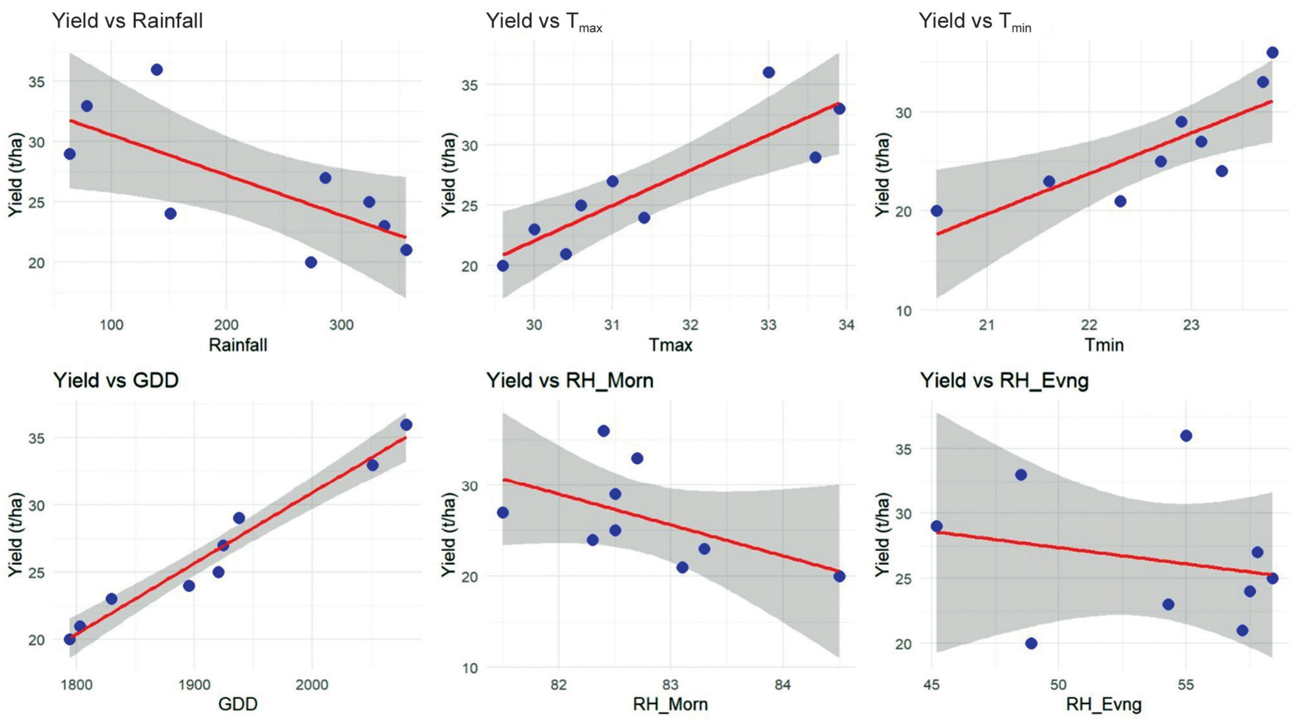

Fig. 2 Yield response to major weather variables through scatter plot and regression lines.
RH, Relative humidity; GDD, Growing degree days.

Table 2 Effect of sowing window and crop geometry on fodder yield (t/ha) of dual purpose sorghum during summer, *kharif* (2022) and *rabi* (2022–23)

Treatment	Summer (yield, t/ha)	Treatment	*Kharif* (yield, t/ha)	Treatment	*Rabi* (yield, t/ha)
Sowing window					
D_1	28.9	D_1, I FN of May	24.3	D_1	21.2
D_2	32.7	D_2, I FN of June	27.4	D_2	22.8
D_3	35.5	D_3, I FN of July	25.5	D_3	19.7
SEd	0.41	SEd	0.328	SEd	0.48
SEM±	0.28	SEM±	0.232	SEM±	0.34
CD (p=0.05)	1.1	CD (p=0.05)	0.912	CD (p=0.05)	1.35
Crop geometry					
S_1	24.0	S_1	18.27	S_1	15.90
S_2	26.8	S_2	22.69	S_2	18.78
S_3	39.1	S_3	30.75	S_3	24.88
S_4	27.6	S_4	20.48	S_4	17.10
S_5	33.2	S_5	27.63	S_5	20.46
S_6	43.6	S_6	34.62	S_6	30.51
SEd	0.53	SEd	0.97	SEd	1.06
SEM±	0.37	SEM±	0.68	SEM±	0.75
CD (p=0.05)	1.2	CD (p=0.05)	2.16	CD (p=0.05)	2.36
Interaction (D × S)	16	Interaction (D × S)	NS	Interaction (D × S)	NS
SEd	1.97	SEd	1.14	SEd	1.98
CD (p=0.05)	4.21	CD (p=0.05)	2.40	CD (p=0.05)	4.21

Treatment details are given in Table 1.

the growing season likely promoted higher leaf to stem ratio and delayed lignification resulting in higher crude protein, lower CF and higher TDN during respective seasons and respective sowing windows. Mahmood and Honermeier (2012) reported that crude protein content was influenced significantly by the time of sowing and among different sowing dates (May 16th, May 29th, June 7th), highest crude protein content was recorded when sowing was taken on June 7th. As winter transitions to spring, temperatures generally start to rise. Warmer temperatures stimulate plant growth and increase the metabolic activity of plants. This results in the accumulation of more carbohydrates and other nutrients in plant tissues, leading to higher TDN levels during summer season compared to other seasons (Pupo *et al.* 2022).

Among various spacing evaluated, the highest CP was recorded with wider spacing of 45 cm × 15 cm while lowest CF and highest TDN were recorded with closer spacing of 30 cm × 5 cm spacing in green fodder during all the three seasons under study. Dry matter fraction forms the basis of crude protein yield. Higher CP was witnessed due to well-established roots and shoots under optimal spacing. Shivprasad and Singh (2017) observed that with decrease in inter-row spacing from 40–20 cm, there was a decrease in crude protein content from 7.8–6.28%. Sivakumar *et al.* (2022) reported that wider spacing of 40 cm × 15 cm obtained higher stem girth (2.21 cm), and crude protein yield (1.54 t/ha) compared to other closer spacing. Avelino *et al.* (2021) reported a reduction in CF content with increasing plant density, attributing this to a dilution of stem (culm) material in the overall plant composition.

Economics: The different sowing windows and crop geometry significantly exert influence on economics (Fig. 3). Overall, the highest gross returns of ₹94,177/ha was achieved with crops sown in the I FN of April using a spacing of 30 cm × 5 cm (D_3S_6), although this treatment incurred the highest cultivation cost (₹35,812/ha). This treatment yielded a higher benefit-cost ratio of 2.63. Conversely, sowing sorghum in the I FN of February with a spacing of 45 cm × 15 cm (D_1S_1) resulted in the lowest gross returns (₹42,811/ha). In the *kharif* season, sowing sorghum in the first fortnight of June with a spacing of 30 cm × 5 cm (D_2S_6) resulted in higher gross returns of ₹74,267/ha. In the *rabi* season, September sowing with 30 cm × 5 cm crop geometry produced gross returns of ₹64,160/ha. The benefit-cost ratio remained similar at 2.13 for both seasons during their respective sowing windows, despite higher yields in *kharif* compared to *rabi*. This difference in yields is attributed to the lower cost of cultivation in the *rabi* season (30,116 ₹/ha) compared to the *kharif* season (34,912 ₹/ha), which is due to a lower

Table 3 Effect of sowing window and crop geometry on crude protein, crude fibre and total digestible nutrients (%) content in green fodder of dual-purpose sorghum during summer, *kharif* (2022) and *rabi* (2022–23)

Treatment	Summer			Treatment	*Kharif*			Treatment	*Rabi*		
	CP	CF	TDN		CP	CF	TDN		CP	CF	TDN
Sowing window											
D_1	5.97	28.66	60.38	D_1	5.68	29.81	59.31	D_1	5.37	29.99	58.84
D_2	6.79	28.30	61.26	D_2	6.62	28.49	61.73	D_2	5.63	29.28	59.44
D_3	7.15	27.96	63.00	D_3	6.10	29.43	59.97	D_3	4.74	30.84	58.32
SEd	0.11	0.17	0.68	SEd	0.13	0.26	0.63	SEd	0.13	0.30	0.33
SEM±	0.07	0.122	0.14	SEM±	0.089	0.182	0.131	SEM±	0.092	0.214	0.189
CD (*p*=0.05)	0.30	0.48	1.90	CD (*p*=0.05)	0.35	0.71	1.75	CD (*p*=0.05)	0.36	0.84	0.93
Crop geometry											
S_1	8.04	29.43	59.74	S_1	7.15	30.39	58.62	S_1	6.54	31.22	57.02
S_2	7.33	28.98	60.46	S_2	6.85	30.02	59.28	S_2	6.25	30.71	57.86
S_3	5.78	27.57	62.59	S_3	5.35	28.46	61.53	S_3	4.37	29.29	59.91
S_4	7.20	28.78	61.00	S_4	6.67	29.68	59.62	S_4	5.68	30.49	58.24
S_5	6.40	28.35	61.59	S_5	6.07	29.25	60.60	S_5	5.04	30.14	59.13
S_6	5.07	26.73	63.90	S_6	4.70	27.64	62.37	S_6	3.60	28.39	61.04
SEd	0.29	0.63	0.756	SEd	0.14	0.56	0.50	SEd	0.16	0.79	0.62
SEM±	0.205	0.447	0.28	SEM±	0.101	0.395	0.186	SEM±	0.111	0.563	0.361
CD (*p*=0.05)	0.64	1.41	1.68	CD (*p*=0.05)	0.32	1.24	1.12	CD (*p*=0.05)	0.35	1.77	1.39
Interaction (D × S)	NS	NS	NS	Interaction (D × S)	NS	NS	NS	Interaction (D × S)	NS	NS	NS
SEd	0.38	1.06	1.27	SEd	0.26	1.12	1.35	SEd	0.35	1.08	0.64
CD (*p*=0.05)	0.82	2.24	2.9	CD (*p*=0.05)	0.58	2.39	3.03	CD (*p*=0.05)	0.78	2.32	1.45

CP, Crude protein; CF, Crude fibre; TDN Total digestible nutrients. Treatment details are given in Table 1.

Fig. 3 Effect of sowing window and crop geometry on the cost of cultivation, gross returns and B:C ratio of sorghum. Treatment details are given in Table 1.

recommended dose of fertiliser in *rabi* compared to *kharif*. Saptal *et al.* (2024) indicated that maximum B:C was fetched in July 10 sown fodder maize (2.03 and 2.25) which were at par with June 25 sowing in Haryana.

The study concluded that significant improvements in green fodder production and quality under irrigated conditions were achieved with sowing during the first fortnight of April, coupled with a narrow spacing of 30 cm × 5 cm with a yield of 35.5 t/ha, low crude fibre (27.96%), higher crude protein (7.15) and higher total digestible nutrients (63%). This combination was found to optimise crop growth and fodder yield. Similarly, under rainfed conditions, sowing in the second fortnight of September demonstrated potential for higher green fodder yield (22.8 t/ha) while also proving to be economically viable (B:C ratio-2.13).These findings provide valuable guidance to farmers in choosing best time of sowing and supports efficient land use through best spacing options, reducing seasonal feed shortage. It also highlights the importance of tailoring sowing time and spacing to specific environmental conditions to maximise productivity and cost-effectiveness.

REFERENCES

Agele S, Taiwo G and Akinseye M. 2025. Growth and yield responses of sorghum [*Sorghum bicolor* (L.) Moench] varieties to sowing time in a rainforest zone of Nigeria. *Scientific Reports* **15**(1): 1–16. https://doi.org/10.1038/s41598-025-14447-5

Ahmad S, Khalid A, Picard M, Martin P, Ishtiaq U, Gull U and ul Haq M Z. 2025. Effects of planting dates on biomass and quality of sorghum and sorghum-sudangrass hybrids under semi-arid conditions. *American Journal of Plant Sciences* **16**(5): 537–58. https://doi.org/10.4236/ajps.2025.165040

Ajaj H A, Mohammed Y A, Alrubaya A A and Addaheri A M. 2021. Effect of planting dates on the growth, yield and quality of three cultivars of sorghum (*Sorghum bicolor* L. Moench). *IOP Conference Series: Earth and Environmental Science* **904**(1): 012019.

Akinseye F M, Ajeigbe H A, Kamara A Y, Omotayo A O, Tofa A I and Whitbread A M. 2023. Establishing optimal planting windows for contrasting sorghum cultivars across diverse agro-ecologies of north-eastern Nigeria: A modelling approach. *Agronomy* **13**(3): 727. https://doi.org/10.3390/agronomy13030727

Altman A W, Vanzant E S, McLeod K R and Harmon D L. 2022. *In vitro* measurements of true digestibility and products of digestion using multiple cultivars of non-extracted and CBD-extracted industrial hemp biomass (*Cannabis sativa*). *Frontiers in Animal Science* **3**: 915916. https://doi.org/10.3389/fanim.2022.915916

Ammaiyappan A, Geethalakshmi V, Bhuvaneswari K, Kalarani M K, Thavaprakaash and Prahadeeswaran M. 2025. Influence of sowing dates and nitrogen levels on the performance of summer-irrigated sorghum in the western agroclimatic zone of Tamil Nadu. *Plant Science Today* **12**(3): 1–8. https://doi.org/10.14719/pst.7866

Avelino P M, Neiva J N M, de Araujo V L, Alexandrino E, Bomfim M A and Restle J. 2021. Chemical composition of silage sorghum hybrids grown at different densities. *Revista Ciência Agronômica* **42**(1): 208–15.

Baghdadi A, Halim R A, Majidian M, Daud W N and Ahmad I. 2012. Forage corn yield and physiological indices under different plant densities and tillage systems. *Journal of Food, Agriculture and Environment* **10** (3–4):707–12.

Goering H K and Van Soest P J. 1970. *Forage Fibre Analyses (Apparatus, Reagents, Procedures, and Some Applications)*. US Agricultural Research Service, Washington DC.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, 2nd edn, pp. 639. John Willey and Sons, New York.

Herrera D M, Peixoto W M, Abreu J G D, Reis R H D, Cabral C E, Barros L V D, Klein V A and Passos E F D. 2024. Sorghum densification with changes in plant spacing arrangement: Productivity and qualitative characteristics of silage material. *Agronomy* **14**(2): 358. https://doi.org/10.3390/agronomy14020358

Humphries E. 1956. Mineral components and ash analysis. *(In) Modern Methods of Plant Analysis*, Vol. 1, pp. 468–502. Springer, Berlin.

Kim M and Sung K. 2023. Assessment of weather events impacts on forage production trend of sorghum-sudangrass hybrid. *Journal of Animal Science and Technology* **65**(4): 792. https://doi.org/10.5187/jast.2023.e3

Mahalle G, Chorey A, Darekar N and Dangore S. 2022. Influence of various sowing dates on growth, yield and economics of different fodder sorghum genotypes. *The Pharma Innovation Journal* **11**(4): 2110–12.

Mahmood A and Honermeier B. 2012. Effect of row spacing and cultivar on biomass yield and quality of *Sorghum bicolor* L. Moench. *Journal of Cultivated Plants* **64**(7): 250.

Prasad V R, Govindaraj M, Djanaguiraman M, Djalovic I, Shailani A, Rawat N, Singla-Pareek S L, Pareek A and Prasad P V. 2021. Drought and high temperature stress in sorghum: physiological, genetic, and molecular insights and breeding approaches. *International Journal of Molecular Sciences* **22**(18): 9826. https://doi.org/10.3390/ijms22189826

Pupo M R, Wallau M O and Ferraretto L F. 2022. Effects of season, variety type, and trait on dry matter yield, nutrient composition, and predicted intake and milk yield of whole-plant sorghum forage. *Journal of Dairy Science* **105**(7): 5776–85.

Redfearn D D, Zhang H and Caddel J L. 2004. *Forage Quality Interpretations*. Division of Agricultural Sciences and Natural Resources, Oklahoma State University, Oklahoma.

Satpal, Satyajeet, Kumar S, Neelam, K K Bhardwaj and Anil K. 2024. Sowing date, crop geometry and fertilizer levels influenced yield, productivity and economics of fodder maize. *Forage Research* **50**(3): 278–83.

Shivprasad M and Singh R. 2017. Effect of planting geometry and different levels of nitrogen on growth, yield and quality of multicut fodder sorghum [*Sorghum bicolor* (L.) Monech]. *Journal of Pharmacognosy and Phytochemistry* **6**(4): 896–99.

Sivakumar S D, Karthikeyan R and Babu C. 2022. Effect of spacing and fertilizer levels on growth, yield and economics of fodder maize pre-release culture TNFM 131-9. *Journal of Current Crop Science and Technology* **109**: 25–30. https://doi.org/10.29321/MAJ.10.000664

Sree Y S, Karthikeyan R, Sivakumar S D, Djanaguiraman M, Thirunavukkarasu M, Boomiraj K and Sangeetha S P. 2023. Performance of dual-purpose sorghum (*Sorghum bicolor*) under different sowing windows and crop geometry. *Journal of Applied and Natural Science* **15**(3): 1276–81. https://doi.org/10.31018/jans.v15i3.4827

Umesh M R, Angadi S, Begna S and Gowda P. 2022. Planting density and geometry effect on canopy development, forage yield and nutritive value of sorghum and annual legumes intercropping. *Sustainability* **14**(8): 4517. https://doi.org/10.3390/su14084517

Upadhyaya H D, Vetriventhan M and Azevedo V C. 2021. Variation for photoperiod and temperature sensitivity in the global mini core collection of sorghum. *Frontiers in Plant Science* **12**: 571243. https://doi.org/10.3389/fpls.2021.571243

Widodo S, Indriatama W M, Anggraeny Y N, Sholikin M M, Jayanegara A and Wahyono T. 2025. Forage biomass and nutrient quality in brown midrib (BMR) compared to conventional sorghum: A meta-analysis approach. *Journal of Advanced Veterinary and Animal Research* **12**(1): 157. https://doi.org/10.5455/javar.2025.l883