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Effects of Planting Dates on Biomass and Quality of Sorghum and Sorghum-Sudangrass Hybrids under Semi-Arid Conditions

Sohail Ahmad[1,2], Ayesha Khalid[3], Maxime Picard[4], Patrick Martin[4*], Uzair Ishtiaq[5,6], Umair Gull[1*], Muhammad Zia ul Haq[1]

[1]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
[2]Institute of Soil and Water Conservation, Northwest A&F University, Xianyang, China
[3]College of Horticulture, Northwest A&F University, Xianyang, China
[4]Transformations & Agroressources (ULR7519), Université d'Artois-UniLaSalle, Bethune, France
[5]Department of Research and Development, Paktex Industries, Gujranwala, Pakistan
[6]Department of Life Sciences, University of Management and Technology, Lahore, Pakistan
Email: *patrick.martin@univ-artois.fr, *umairgull@uaf.edu.pk

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Abstract

Sorghum productivity is highly influenced by temperature fluctuations, which is a critical issue in the context of climate change. To optimize sowing time and evaluate the comparative performance of sorghum and sorghum × Sudan grass hybrids (SSH), a field experiment was conducted during the Kharif season. The main plot treatments included two planting dates (31st March and 29th April 2023), while the subplots included three hybrids (Sorgo Sweet, SS-1000, Jumbo) and Sorghum-2011. Data was analyzed using Fisher's analysis of variance, with treatments compared through the least significant difference (LSD) at a 5% probability level. Results showed that the SS-1000 hybrid excelled in key traits, including leaf count, plant height, tiller production, green fodder yield, and lower hydrocyanic acid (HCN) concentration, followed by Sorgo Sweet, Jumbo. Sorghum-2011, however, performed suboptimally across all measured traits. Additionally, the 31st March planting date consistently outperformed the 29th April planting, producing higher green fodder yields, better plant height, and lower HCN concentrations. These findings highlight the importance of selecting optimal sowing dates and using sorghum hybrids to enhance fodder crop productivity and safety, especially in the face of evolving climatic challenges.

Keywords

Sorghum Productivity, Sowing Time Optimization, Hydrocyanic Acid (HCN), Green Fodder Yield

1. Introduction

Livestock farming in Pakistan faces a critical challenge due to limited fodder production, with only 2.45 million hectares allocated for fodder crops (GOP, 2022). This area is insufficient to meet the growing nutritional requirements of the sector. In Pakistan, fodder is divided into two cropping seasons: Kharif (April-June sowing, October-December harvesting) and Rabi (October-March). Common Kharif forages include sorghum, millet, and guar, while Rabi forages consist of lucerne and berseem. The country experiences significant fodder shortages during the transitional periods from mid-May to mid-July and November to January, leading to increased competition for resources and negatively impacting livestock nutrition [1]. In this context, the development of high yielding, multi-cut, and superior-quality fodder varieties, particularly hybrids, is a key priority. In Kharif season planting of a wide variety of forages, such as sorghum, millet, and guar, is done with the intention of satisfying the dietary needs of livestock animals [2]. To address this issue, the development of high yielding, multi-cut, and superior-quality fodder varieties, particularly hybrids, has become a key priority. Sorghum (Sorghum bicolor L.) is a major Kharif forage crop cultivated in both irrigated and barani regions. It ranks fifth among the world's most important cereal crops, following wheat, rice, maize and barley [3] [4].

The sorghum crop is characterized by its tolerance to environmental conditions that are not suitable for the production of other summer crops (maize and soybeans), especially heat, drought, and soil salinity. For this reason, it is often referred to as "Camel crop" [5]. It is suitable for salty soil in arid and semi-arid areas and has a high nutritional value comparable to maize [6] [7]. To bridge the gap between feed supply and the rising demands of the livestock sector, the introduction of multi-cut hybrids is essential [8]. Enhancing forage yield through improved cultivars is a crucial step in meeting these demands [9]. Among these hybrids (Sudan grass, Rhodes grass, Napier grass, sorghum-Sudan grass), sorghum-Sudan grass (SSG) is a key summer crop in semi-arid climates, offering superior resilience to drought, extreme temperatures, pests, and diseases. Its high biomass yield and ratooning ability make it a reliable year-round feed option.

SSG hybrids provide two or three cuts per season and can be stored as silage or green chops, reducing labor and seed costs [10]-[13]. However, to fully realize the potential of these hybrids, their performance must be rigorously evaluated under varying environmental conditions before making recommendations to farmers [14]. Factors such as genotype, planting time, nutrition, irrigation, environmental conditions-light, temperature, and water play a critical role in determining sorghum fodder yield and quality [15] [16]. Currently, fodder crops occupy only 2.45 million hectares, representing 11% of the country's total cultivated area, with an annual yield of approximately 55.47 million tons of green fodder (Economic Survey, 2022). This production is insufficient to meet the growing nutritional demands of the livestock sector. However, there is a lack of comprehensive research on the interaction between planting dates and cultivars in the context of Pakistan's unique agro-climatic conditions. To enhance crop yield and quality, it is imperative to explore alternative strategies, including optimizing planting dates. This becomes especially important with the introduction of various cultivars and hybrids into Pakistan, as well as the development of new cultivars by plant breeders. The unique research angle of this study lies in its focus on optimizing planting dates for newly introduced and locally developed sorghum cultivars and hybrids, particularly SSG, to maximize yield and quality under Pakistan's specific environmental conditions. The hypothesis of this study is that the interaction between planting dates and cultivars significantly influences sorghum fodder yield and quality, and that identifying the optimal planting window for specific cultivars will enhance productivity and resource efficiency.

Consequently, evaluating the efficiency of these cultivars and their ability to fully realize their potential under prevailing environmental conditions is essential. Enhancing their efficiency by utilizing available growth resources can significantly increase productivity per unit area. The choice of the optimal planting date holds as much significance as selecting the right cultivar and applying proper nutrition, as all these factors work together to maximizing production. This study was therefore designed to assess the impact of different planting dates and to identify the best performing cultivars in terms of yield and quality, while being suitable for the specific conditions of the research area. Additionally, it aims to examine the interactions between planting dates and cultivars, offering valuable insights for optimizing agricultural practices.

2. Materials and Methods

2.1. Study Area

The field experiment was conducted during the Kharif season of 2023 at the Student Research Farm, Department of Agronomy, University of Agriculture Faisalabad, Pakistan. The experimental site is located at an elevation of 214 meters above sea level, with geographical coordinates of 31.30˚N latitude and 73.05˚E longitude. To assess the soil characteristics at the experimental site, composite soil samples were collected from two depths (0 - 15 cm and 15 - 30 cm) prior to planting for physio-chemical analysis. Composite soil sample sent to Ayub Agriculture soil testing lab for soil analysis. The results of the soils analysis are summarized in **Table 1**. Meteorological data, including daily mean temperature (˚C), relative humidity (%), rainfall (mm), and sunshine duration (hours) recording during the experimental period, are presented in **Figure 1**, providing insight into the growing conditions during the study period.

Table 1. Soil physio-chemical analysis of the experimental site.

Characteristics	Unit	Values
Nitrogen (N)	mg kg^{-1}	25.4
Phosphorus (P)	mg kg^{-1}	33.5

Continued

Potassium (K)	mg kg^{-1}	162
Saturation	%	36
EC	dSm^{-1}	1.09
Organic matter	%	1.61
Texture	-	Loam
pH	-	8.2

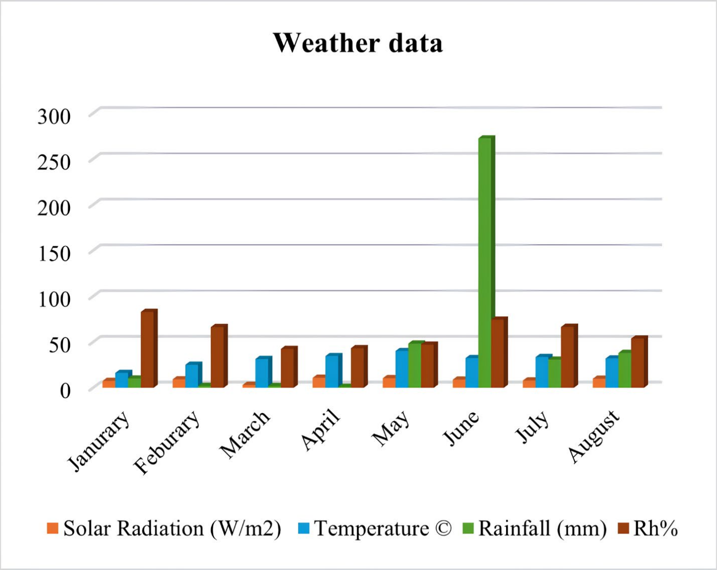

Figure 1. Weather data of sorghum growth period 2023.

2.2. Experimental Setup

The experiment was conducted using a randomized complete block design (RCBD) with a split-plot arrangement. Two planting dates (31st March and 29th April) were allocated to the main plots, while three sorghum-Sudan grass hybrids (Sorgo Sweet (USA), SS-1000 (South Africa), Jumbo (Australia), and Sorghum-2011 were assigned to the subplots and compared to Sorghum-2011. The experiment was conducted from 31st March to 30th August at the Student Research Farm, utilizing a Randomized Complete Block Design (RCBD) under a split-plot arrangement. The study comprised 8 treatments, each replicated 3 times to minimize experimental errors and ensure statistical robustness. The gross experimental area measured 23.5 m × 26 m (611 m^2), with individual blocks sized at 26 m × 5.88 m (153 m^2). Each block was further divided into 8 plots, corresponding to the 8 treatments, with each net plot measuring 6.0 m × 1.8 m (10.8 m^2). The row-to-row distance was maintained at 30 cm, and line sowing was carried out using a single-row hand drill at a uniform seed rate of 25 kg ha^{-1}. Fertilizer was applied at the recommended rates of 80 kg nitrogen (N) and 60 kg phosphorus (P_2O_5) per hectare. Standard agronomic practices, including irrigation and weeding, were uniformly applied across all treatments throughout the growing season.

2.3. Data Collection and Analysis

At the end of each growth period, data were collected on various growth and yield parameters. Plant samples were harvested from four randomly selected rows within a 1 m^2 area in each plot to assess biomass. The first cut data was recorded 60 days after sowing, followed by the second cut 45 days after the first cut, and the third cut 45 days after the second cut. Subsequently, ten plants per plot were randomly selected to record plant height (cm), number of tillers per plant, number of leaves per plant, and green fodder yield ($t \cdot ha^{-1}$). To determine the crude protein content of the leaves, the Kjeldahl method was employed with a conversion factor of 6.25, based on the total nitrogen content [17]. For the analysis of forage neutral detergent fibre (NDF) and acid detergent fibre (ADF) fractions, a sequential approach following the AOAC guidelines was followed.

$$\text{Green fodder yield}\left(\text{t/ha}\right) = \text{Green fodder yield} \times 10000$$

$$\text{Nitrogen}\left(\%\right) = \frac{0.1\ \text{ml}\ \text{NH}_2\text{SO}_4 \times 0.00014 \times 250}{\text{Weight of sample} \times \text{volume of diluted sample}}$$

$$\text{Crude protein}\left(\%\right) = \text{Nitrogen}\left(\%\right) \times 6.25$$

$$\text{NDF}\left(\%\right) = \frac{\text{Weight of crucible} + \text{Dried NDF residues} - \text{Weight of crucible}}{\text{Weight of sample}} \times 100$$

$$\text{ADF}\left(\%\right) = \frac{\text{Ash weight with crucible after treatment} - \text{Crucible weight}}{\text{Weight of sample}} \times 100$$

The determination of total cyanide content (**Figure 2**, **Figure 3**) in the young sprouted leaves of sorghum was measured according to the method established by Bradbury *et al.* [18]. One gram of moist picric acid was dissolved in 100 ml of 2.5% (w/v) sodium carbonate, resulting in a yellow picrate solution. Young leaves were thoroughly chopped and ground, and 10 g of the resulting material was weighed using a portable plastic balance. This ground leaf sample was placed in a transparent Falcon test tube. Rectangular pieces (30 mm × 10 mm) of Whatman 3 mm filter paper were immersed in this solution for 30 seconds, then air-dried after removal. These pieces were attached to one end of a paper tape strip, with the other end affixed to the test tube's lid from the inner side. A similar sample without leaves served as a blank control. After standing for 24 h at room temperature, the paper tape was carefully removed. The picrate paper was then cut and soaked in 10 ml of distilled water for 30 minutes, with gentle shaking using a rotary vortex mixer. The same process was applied to the blank picrate paper. After removal, the samples were centrifuged at 6000 rpm for 7 minutes, and the picrate solution was filtered through filter paper. Absorbance at 520 nm was measured for the blank sample using a spectrophotometer. Subsequently, absorbance values for the other picrate solutions were then measured, and the absorbance of the blank sample was subtracted from each to obtain the final readings. The total cyanide content in parts per million (ppm) was calculated using the following formula:

$$\text{Total cyanide content} = 358 \times \text{absorbance}$$

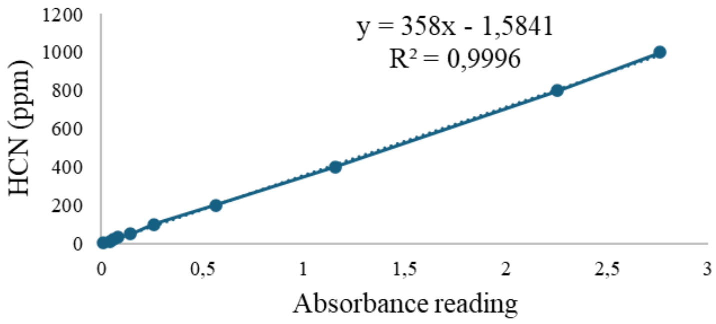

Figure 2. Standard curve used to calculate the total cyanide content.

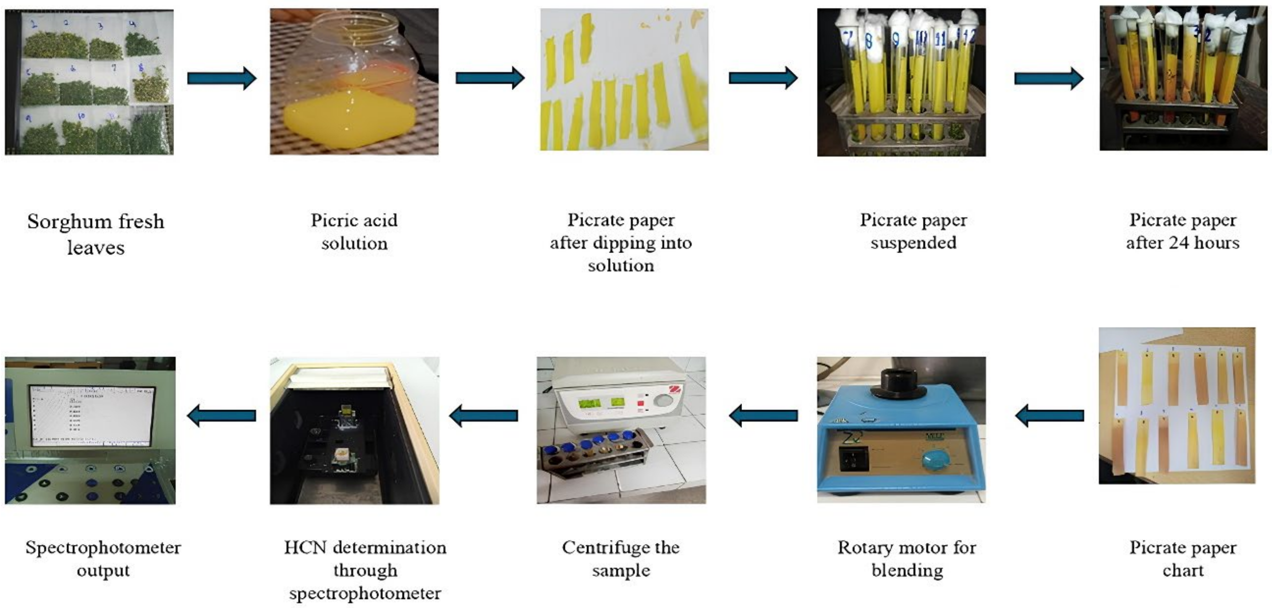

Figure 3. Schematic representation of the process for determination of total cyanide content in sorghum leaves using the picrate method.

2.4. Statistical Analysis

All collected data were statistically analyzed using analysis of variance (ANOVA) to determine the significance of treatment effects. Mean comparisons were performed using the least significant difference (LSD) test at a 5% probability level, to assess differences between planting dates and hybrids. Statistical analyses were conducted using the software package Statistix 10 [17] [19].

3. Results

3.1. Plant Population (%)

The results of this study (Table 2, Table 3) showed that the plant population was unaffected by the planting date, with no significant differences observed in the germination rates of sorghum and sorghum-Sudan grass hybrids. This suggests that the timing of planting had no discernible effect on seed germination. The optimal condition for Sorghum Sweet germination is at least 10 h of sunshine per day, a threshold that was consistently met in March and April across Pakistan. Casto et *al.* [20] reported that the optimal temperature range for germinating sorghum seeds is between 24˚C and 30˚C. In Pakistan, temperatures in March and April typically exceed 25˚C, as shown in **Figure 1**. The favorable sunlight conditions during these months likely contributed to the lack of significant differences in germination rates between the planting dates.

Table 2. Analysis of variance (ANOVA) for plant population (%).

SOV	DF	SS	MSS	F-ratio
Replication	2	345.25	172.62	
Planting dates	1	888.17	888.17	4.61^{NS}
Error Replication*Planting dates	2	385.58	192.79	
Cultivars	3	1005.67	335.22	1.91^{NS}
Planting dates*Cultivars	3	385.50	128.50	0.55^{NS}
Error Replication*Planting dates*Cultivars	12	2105.83	175.48	
Total	23	5116		

* = $p \leq 0.05$, ** = $p \leq 0.01$, NS = non-significant.

Table 3. Influence of planting dates on plant population (%) of sorghum and sorghum-Sudan grass hybrids.

Cultivars	Planting dates		Means
	31st March	29th April	
Sorgo Sweet (USA)	86.00	92.66	89.33
SS-1000 (South Africa)	79.33	85.00	82.16
Jumbo (Australia)	88.33	99.00	93.66
Sorghum-2011 (Pakistan)	64.00	89.66	76.83
Means	79.41	91.58	

3.2. Plant Height (cm)

For plant height, the planting date had a significant effect across all three cuts (**Table 4**, **Table 5**). In the first cut, the 31st March planting date produced a plant height of 199.67 cm, outperforming the 29th April planting, which resulted in 172.25 cm. Similarly, in the second cut, plants from the 31st March sowing reached 205.00 cm, while those sown on 29th April were shorter at 144.83 cm. In the third cut, the 31st March planting again showed superior performance with a height of 115.67 cm, compared to 90.89 cm for the 29th April planting.

Regarding cultivars, SS-1000 consistently had the greatest plant height across all cuts. In the first cut, SS-1000 reached 208.67 cm, significantly taller than Sorghum-2011, which measured 174.67 cm. In the second cut, SS-1000 recorded 211.00 cm, while Sorghum-2011 measured 175.17 cm. In the third cut, SS-1000 maintained its lead at 108.83 cm, while Sorghum-2011 did not produce data due to its limited growth potential. Overall, the 31st March planting date outperformed the

29th April in all three cuts, with SS-1000 consistently achieving the greatest plant height. However, the particularly poor performance of Sorghum-2011—especially its complete failure to produce data in the third cut—raises important questions about its adaptability. This cultivar's limitations stem from genetic factors, as varietal differences in plant height and growth patterns are primarily determined by genotype. Sorghum-2011 may lack the vigorous growth genes present in SS-1000, or it might be poorly adapted to local environmental conditions. Its inability to maintain growth through multiple cuts suggests potential weaknesses in stress tolerance or regrowth capacity compared to the more robust SS-1000 hybrid. Changing planting date could influence growth process, particularly with changes in environmental temperature. The significant increase in these attributes under early sown crops might be due to favorable environmental conditions and better translocation of photosynthates during the reproductive phase of the crop [21]. The owest plant height was recorded in Jumbo (Australia) in both years during all growth stages of crop. This could be attributed to genetic factors. The variation in the plant's height and panicle length could be explained by the variation in their genotype make-up [22]. Similar results for date of sowing for plant height were given by Dhar *et al.* and Sonwar *et al.* [23] [24].

Table 4. Analysis of variance (ANOVA) for plant height (cm).

		1st cut	2nd cut	3rd cut
SOV	DF	F-ratio	F-ratio	F-ratio
Replication	2			
Planting dates	1	73.73**	70.55**	84.43**
Error Replication*Planting dates	2			
Cultivars	3	6.62**	8.15**	22.65**
Planting dates*Cultivars	3	0.33^{NS}	0.84^{NS}	7.13**
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = p ≤ 0.05, ** = p ≤ 0.01, NS = non-significant.

Table 5. Influence of planting dates on plant height (cm) of sorghum and sorghum-Sudan grass hybrids.

Cultivars	1st cut		Mean	2nd cut		Mean	3rd cut		Mean
	31st March	29th April		31st March	29th April		31st March	29th April	
Sorgo Sweet (USA)	201.00	168.83	184.67 B	196.33	136.67	166.50 B	117.67 b	101.00 c	109.33 A
SS-1000 (South Africa)	218.33	199.00	208.67 A	239.30	182.67	211.00 A	127.67 a	90.00 cd	108.83 A
Jumbo (Australia)	183.00	147.00	165.00 B	185.54	111.00	148.17 B	101.67 c	81.67 d	91.67 B
Sorghum-2011 (Pakistan)	196.33	174.67	185.50 B	201.67	149.00	175.17 B	----------	---------	---------
Mean	199.67 B	172.25 A		205.58 A	144.83 B		115.67 A	90.89 B	

3.3. Number of Leaves Per Plant

For the number of leaves, the planting date showed varying effects across the cuts (Table 6, Table 7). In the first cut, the planting date was non-significant. However, in the second cut, the 31st March planting showed a highly significant effect ($p < 0.01$), producing a greater number of leaves compared to the 29th April planting. In the third cut, the planting date once again showed no significant effect. Regarding cultivars, SS-1000 consistently produced the highest number of leaves across all cuts. In the first cut, SS-1000 recorded 10.70 leaves per plant, while Sorghum-2011 had the fewest at 8.66 leaves per plant. In the second cut, SS-1000 again led with 11.66 leaves, while Sorghum-2011 had 9.33 leaves. In the third cut, Sorgo Sweet recorded the highest number of leaves at 10.16, non-significant compared to SS-1000, while Jumbo had 7.50 leaves. Sorghum-2011 did not produce any data in the third cut. Overall, SS-1000 showed the highest leaf count throughout the cuts, and the 31st March planting date performed better than the 29th April planting in the second cut.

Table 6. Analysis of variance (ANOVA) for No. of leaves/plant.

		1st cut	2nd cut	3rd cut
SOV	**DF**	**F-ratio**	**F-ratio**	**F-ratio**
Replication	2			
Planting dates	1	6.91^{NS}	154.71**	12^{NS}
Error Replication*Planting dates	2			
Cultivars	3	17.43**	4.68*	33.38**
Planting dates*Cultivars	3	3.87*	3.37*	4.15*
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = $p \leq 0.05$, ** = $p \leq 0.01$, NS = non-significant.

Table 7. Influence of planting dates on number of leaves per plant of sorghum and sorghum-Sudan grass hybrids.

Cultivars	1st cut		Mean	2nd cut		Mean	3rd cut		Mean
	31st March	29th April		31st March	29th April		31st March	29th April	
Sorgo Sweet (USA)	10.70 a	10.11 ab	10.43 A	14.00 a	9.00 cd	11.50 A	10.37 ab	9.04 bc	9.70 A
SS-1000 (South Africa)	10.85 a	10.56 ab	10.70 A	15.00 a	8.33 d	11.65 A	11.30 a	9.00 bc	10.15 A
Jumbo (Australia)	9.36 bc	10.22 ab	9.77 B	11.00 bc	7.30 d	11.33 A	7.64 cd	7.31 d	7.50 B
Sorghum-2011 (Pakistan)	8.40 d	8.81 cd	8.66 C	13.00 ab	10.00 c	9.33 B	----------	---------	---------
Mean	9.82	9.92		13.31 A	8.58 B		9.77	8.44	

Many researchers suggest that early sorghum plants have a coleoptile leaf that orients growth towards light sources, optimizing photosynthesis and enabling greater carbohydrate production. This leads to a higher leaf count as the plant matures. Photorespiration also plays a vital role, as early growing tends to produce higher biomass. In contrast, late-emerging sorghum often lacks these advantages, leading to a reduced number of leaves. The timing of growth is crucial in determining leaf production in sorghum [25] [26]. Sorghum-2011 poor performance in leaf production, regardless of planting date, underscores the importance of selecting cultivars with both optimal growth timing and inherent genetic capacity for sustained leaf development.

3.4. Number of Tillers (Per Plant)

The ANOVA analysis for the number of tillers across three cuts showed that the planting date was non-significant throughout (**Table 8**, **Table 9**). However, significant differences were observed among cultivars. In the first cut, SS-1000 had the highest mean tillers per plant (1.99), followed by Jumbo with 1.77, while Sorghum-2011 recorded the lowest (0.16). Sorgo Sweet, SS-1000, and Jumbo were non-significant compared to each other but significantly different from Sorghum-2011. In the second cut, cultivars were highly significant ($p < 0.01$), with Jumbo

Table 8. Analysis of variance (ANOVA) for No. of tiller/plant.

		1st cut	2nd cut	3rd cut
SOV	**DF**	**F-ratio**	**F-ratio**	**F-ratio**
Replication	2			
Planting dates	1	0.20^{NS}	2.98^{NS}	8.86^{NS}
Error Replication*Planting dates	2			
Cultivars	3	13.33*	36.16**	33.96**
Planting dates*Cultivars	3	1.41^{*}	4.84**	7.18^{**}
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = p ≤ 0.05, ** = p ≤ 0.01, NS = non-significant.

Table 9. Influence of planting dates on number of tillers per plant of sorghum and sorghum-Sudan grass hybrids.

Cultivars	**1st cut**		**Mean**	**2nd cut**		**Mean**	**3rd cut**		**Mean**
	31st March	**29th April**		**31st March**	**29th April**		**31st March**	**29th April**	
Sorgo Sweet (USA)	3.99 a	2.86 a	1.93 A	4.00 ab	5.33 a	4.66 A	3.33 b	3.66 bc	3.50 B
SS-1000 (South Africa)	3.33 a	2.66 ab	1.99 A	3.66 b	5.66 ab	4.66 A	3.46 b	3.20 c	3.33 B
Jumbo (Australia)	3.44 a	2.11 a	1.77 A	5.00 ab	6.33 a	5.66 A	5.66 a	4.33 b	5.00 A
Sorghum-2011 (Pakistan)	1.33 b	1.00 c	0.16 B	1.00 c	1.00 c	0.50 B	--------	--------	-------
Mean	3.02	2.15		4.91	3.33		4.15	3.73	

producing the highest mean tillers per plant (5.66), while Sorghum-2011 produced only 0.50 tillers. Similarly, in the third cut, Jumbo again recorded the highest tiller count (5 tillers per plant), whereas Sorghum-2011 produced none, as its potential was exhausted after the second cut. Overall, Jumbo showed consistent performance across the cuts, with mean values of 1.77, 5.66, and 5 tillers per plant, respectively, while Sorghum-2011 consistently lagged, especially after the second cut. The exceptionally poor tillering performance of Sorghum-2011 across all cuts strongly suggests genetic constraints in its tiller initiation and development mechanisms. Unlike Jumbo and SS-1000, which maintained consistent tiller production, Sorghum-2011 near absence of tillers and complete inability to regenerate in later cuts points to fundamental limitations in its meristem activity or resource allocation patterns. Many studies reported that changing the planting date of sorghum generally has a limited impact on the number of tillers produced, despite notable differences observed among various cultivars. This minimal effect is primarily due to sorghum's temperature sensitivity and the inherent genetic traits of each cultivar. The genetic traits of individual cultivars dictate their tiling capacity. Some cultivars are inherently programmed to produce fewer tillers, which lessens the effect of changing the planting date on overall tillers [27] [28]. Additionally, specific sorghum varieties may reach developmental milestones around the same time, reducing variability in tiller production across different planting dates [29].

3.5. Green Fodder Yield (t/ha)

The ANOVA analysis for green fodder yield revealed that the planting date had a significant effect across all three cuts (**Table 10**). The 31st March planting produced higher yields, recording 54.55 t/ha, 47.38 t/ha, and 15.75 t/ha in the first, second, and third cuts, respectively, compared to the 29th April planting. Regarding the cultivars, treatment means comparison (**Table 11**) showed that in the first cut, Sorgo Sweet (54.13 t/ha) and SS-1000 (55.33 t/ha) were significantly superior from Sorghum-2011 (47.63 t/ha). In the second cut, SS-1000 (44.16 t/ha) and Sorgo Sweet were again significantly different from Sorghum-2011 (20.71 t/ha). The interaction was non-significant in the first and third cuts but highly significant in the second cut. Overall, the 31st March planting yielded a cumulative total of 117.68 t/ha, with SS-1000 achieving the highest cumulative yield of 114.49 t/ha, while Sorghum-2011 had the lowest (68.34 t/ha). Our results align with those of Oberoi *et al.* [30], who reported that early sowing significantly increased green fodder yield, with 80.54 tons per hectare in 2016 compared to 63.87 tons per hectare with late sowing. In 2017, yields followed a similar pattern. Many researchers suggest that early sowing of sorghum significantly enhances growth rates and fodder yields by providing favorable temperature and light conditions, which boost photosynthesis and plant development. Therefore, the time of sowing is considered crucial for maximizing fodder production across various sorghum genotypes [31]-[33]. However, Sorghum-2011 poor performance regardless of planting date emphasizes that while sowing time is important, cultivar selection is equally critical, as some genotypes may have inherent yield limitations that cannot be overcome by optimal planting alone. These findings suggest that late sowing negatively impacts both fodder yield and quality due to less favorable environmental conditions.

Table 10. Analysis of variance (ANOVA) for green fodder yield ($t \cdot ha^{-1}$).

		1st cut	**2nd cut**	**3rd cut**
SOV	**DF**	**F-ratio**	**F-ratio**	**F-ratio**
Replication	2			
Planting dates	1	43.71*	31.60**	21.76**
Error Replication*Planting dates	2			
Cultivars	3	4.56*	4.76**	0.40^{NS}
Planting dates*Cultivars	3	0.93^{NS}	0.93*	0.61^{NS}
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = p ≤ 0.05, ** = p ≤ 0.01, NS = non-significant.

Table 11. Influence of planting dates on green fodder yield ($t \cdot ha^{-1}$) of sorghum and sorghum-Sudan grass hybrids.

Cultivars	**1st cut**		**Mean**	**2nd cut**		**Mean**	**3rd cut**		**Mean**
	31st March	**29th April**		**31st March**	**29th April**		**31st March**	**29th April**	
Sorgo Sweet (USA)	57.68	50.66	54.17 A	52.51 ab	26.05 cde	39.28 AB	18.24	5.89	12.06
SS-1000 (South Africa)	58.00	52.61	55.30 A	67.17 a	21.15 de	44.16 A	16.91	7.70	12.30
Jumbo (Australia)	60.00	49.83	54.91 A	40.66 bc	24.10 de	32.38 B	14.09	7.13	10.61
Sorghum-2011 (Pakistan)	50.66	46.66	48.66 C	29.29 cd	12.31 e	20.80 C	--------	--------	-------
Mean	56.58 A	49.94 B		47.40 A	20.90 B		16.41 A	6.90 B	

3.6. Crude Protein (%)

The ANOVA analysis for crude protein percentage across the three cuts indicated that the planting date, cultivars, and their interaction were all highly significant ($p < 0.01$) in both the first and second cuts (Table 12). For the third cut, planting date remained highly significant ($p < 0.01$), while the effect of cultivars was significant ($p < 0.05$), and the interaction between planting date and cultivars was highly significant ($p < 0.01$). The treatment means comparison (Table 13), revealed that the 31st March planting consistently resulted in higher crude protein percentages across all cuts, with values of 7.45%, 7.48%, and 7.80% for the first, second, and third cuts, respectively. In contrast, the 29th April planting produced crude protein percentages of 6.10%, 6.17%, and 6.30% for the first, second, and third cuts, respectively. Among the cultivars, SS-1000 demonstrated the highest crude protein percentages, with mean values of 7.46% in the first cut, 7.49% in the second cut, and 7.50% in the third cut. Conversely, Sorghum-2011 had the lowest crude protein percentages, at 5.90% in the first cut, 5.97% in the second cut, and did not produce any yield in the third cut due to limited growth. Crude protein is essential for livestock, as it supports vital functions such as growth, lactation, reproductive health, metabolism, and tissue repair. Sorghum-2011 substandard protein content (consistently below 6%) falls short of the minimum 7% crude protein generally recommended for quality ruminant feed, potentially limiting its practical utility in dairy or beef production systems. Adequate crude protein intake improves productivity, including improved milk production, weight gain, and overall body condition [34]-[37]. According to Ajaj *et al.* [38], the planting date significantly affects protein content in sorghum by influencing growth, yield, and nutritional quality. Early planting (e.g., late March to early April) typically leads to higher protein levels, attributed to favorable weather conditions during critical growth stages that enhance nutrients uptake and plant health. In contrast, delayed planting (e.g., June) can reduce protein content, as changes in temperature, light, and potential water stress negatively impact the plant's metabolism and protein synthesis [39]. Our study results also align with these findings, showing that early planting dates lead to higher protein content in sorghum. These findings have important practical implications: while optimal planting dates can maximize protein content in most sorghum cultivars, genetically inferior varieties like Sorghum-2011 may never achieve satisfactory protein levels regardless of management practices, making them poor choices for quality fodder production.

3.7. Hydrogen Cyanide (HCN)

The ANOVA analysis for HCN concentration (**Table 14**). showed that in the first and second cuts, the planting date was non-significant, while the cultivars and their interaction were highly significant ($p < 0.01$). In the third cut, the planting date became highly significant ($p < 0.01$), while the cultivars remained non-significant, and the interaction was highly significant ($p < 0.01$).

Table 12. Analysis of variance (ANOVA) for crude protein (%).

		1st cut	2nd cut	3rd cut
SOV	**DF**	**F-ratio**	**F-ratio**	**F-ratio**
Replication	2			
Planting dates	1	74.01**	87.80**	88.94**
Error Replication*Planting dates	2			
Cultivars	3	16.21**	16.51**	5.29*
Planting dates*Cultivars	3	4.85**	6.30**	7.95**
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = $p \leq 0.05$, ** = $p \leq 0.01$, NS = non-significant.

Table 13. Influence of planting dates on crude protein (%) of sorghum and sorghum-Sudan grass hybrids.

Cultivars	1st cut		Mean	2nd cut		Mean	3rd cut		Mean
	31st March	29th April		31st March	29th April		31st March	29th April	
Sorgo Sweet (USA)	7.26 b	6.32 c	6.87 B	7.46 b	6.27 d	6.87 A	7.02 b	6.33 c	6.67 B
SS-1000 (South Africa)	8.66 a	6.26 c	7.46 A	8.72 a	6.28 d	7.49 B	8.16 a	6.44 c	7.46 A
Jumbo (Australia)	7.33 b	6.44 c	6.89 B	7.35 bc	6.58 cd	6.96 B	7.12 b	6.26 c	6.69 B
Sorghum-2011 (Pakistan)	6.39 c	5.40 d	5.90 C	6.40 d	5.54 e	5.97 C	--------	-------	-------
Mean	7.45 A	6.10 B		7.48 A	6.17 B		7.80 A	6.30 B	

Table 14. Analysis of variance (ANOVA) for HCN (ppm).

		1st cut	2nd cut	3rd cut
SOV	DF	F-ratio	F-ratio	F-ratio
Replication	2			
Planting dates	1	1.08NS	1.29NS	61.22**
Error Replication*Planting dates	2			
Cultivars	3	5.96**	5.96**	0.43NS
Planting dates*Cultivars	3	5.33**	5.33**	7.71**
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = p ≤ 0.05, ** = p ≤ 0.01, NS = non-significant.

In the treatment means comparison (Table 15), SS-1000 had the lowest HCN concentrations in the first cut (95.81 ppm) and second cut (92.28 ppm), significantly lower than Sorghum-2011, which had the highest levels (158.12 ppm and 153.83 ppm, respectively). In the third cut, the 31st March planting produced a lower HCN concentration of 114.90 ppm compared to 124.00 ppm for the 29th April planting. Overall, SS-1000 consistently recorded the lowest HCN concentrations across all three cuts (95.81 ppm, 92.28 ppm, 114.90 ppm), while Sorghum-2011 had the highest levels (158.12 ppm, 153.83 ppm, 124.00 ppm). Sorghum-2011 persistently elevated HCN levels across all cuts suggest this cultivar may have: i) higher expression of cyanogenic glycosides, ii) more active β-glucosidase enzymes that release HCN, or iii) weaker regulatory mechanisms for cyanide detoxification compared to other cultivars. These results indicate that planting date significantly affected HCN levels only in the third cut, highlighting the importance of cultivar selection for managing HCN concentrations. Sorghum is a nutritious fodder, however, it contains HCN, which can limit its use due to potential toxicity [40]. The safe HCN threshold in sorghum fodder is 200 mg/kg on a dry weight basis and 500 mg/kg on a fresh weight basis. However, cases of serious illness and fatalities in cattle [41] [42], goats [43], and other grazing animals [44] due to high HCN levels in cyanogenic plants highlight the need for careful HCN monitoring to ensure safe feeding practices [45]. From a practical feeding perspective, Sorghum-2011's higher cyanide potential would necessitate: (1) longer wilting periods before feeding, (2) avoidance of young regrowth, and (3) extra dilution with other forages—management constraints that reduce its utility compared to safer cultivars like SS-1000. Our results on HCN levels align with those reported by Sarfraz *et al.* [46], indicating that HCN content remained within safe limits across all cultivars and both planting dates, presented below in **Table 15**.

Table 15. Influence of planting dates on HCN (ppm) in sorghum and sorghum-Sudan grass hybrids.

Cultivars	1st cut		Mean	2nd cut		Mean	3rd cut		Mean
	31st March	29th April		31st March	29th April		31st March	29th April	
Sorgo Sweet (USA)	84.51	121.58	103.04 B	92.92	125.99	109.45 A	113.41 c	127.00 b	120.00
SS-1000 (South Africa)	78.53	113.21	95.87 B	80.94	106.62	93.78 B	115.33 c	124.00 b	119.00
Jumbo (Australia)	96.47	123.97	110.24 B	92.88	126.38	109.63 A	115.96 c	123.00 b	119.00
Sorghum-2011 (Pakistan)	149.70	137.58	163.64 A	127.11	132.52	129.81 A	---------	---------	-------
Mean	112.30	124.08		98.46	122.87		114.90 B	124.00 A	

3.8. Neutral Detergent (NDF %)

The ANOVA analysis for neutral detergent fiber (NDF) percentage across the three cuts revealed that the planting date was non-significant in the first two cuts, while both cultivars and their interaction were highly significant ($p < 0.01$) (**Table 16**). In the third cut, the planting date became significant ($p < 0.05$), whereas the cultivars and interaction remained non-significant.

Table 16. Analysis of variance (ANOVA) for NDF (%).

		1st cut	2nd cut	3rd cut
SOV	**DF**	**F-ratio**	**F-ratio**	**F-ratio**
Replication	2			
Planting dates	1	12.17^{NS}	14.92^{NS}	29.64*
Error Replication*Planting dates	2			
Cultivars	3	59.12**	25.23**	0.84^{NS}
Planting dates*Cultivars	3	9.84**	3.34**	0.22^{NS}
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = p ≤ 0.05, ** = p ≤ 0.01, NS = non-significant.

In the treatment means comparison (**Table 17**), Sorgo Sweet, SS-1000, and Jumbo all produced significantly lower NDF percentages in the first cut, measuring 52.61%, 50.14%, and 48.60%, respectively, compared to Sorghum-2011, which recorded a higher percentage of 68.39%. The second cut showed similar results, with the same three cultivars outperforming Sorghum-2011 (NDF percentages of 65.32%). However, Sorghum-2011 did not produce a third cut. In the third cut, the 29th April planting yielded a higher NDF content, while the 31st March planting showed better overall performance in reducing NDF levels. Overall, the 31st March planting consistently resulted in lower NDF levels across all three cuts compared to the 29th April planting, highlighting the advantage of earlier planting dates and the superiority of Sorgo Sweet, SS-1000, and Jumbo in managing NDF concentrations compared to Sorghum-2011. The values in the present study are comparatively lower than those reported by Carmi *et al.* [47], Colombo *et al.* [48], and Singh and Shukla [49], who found 62.80%, 62.60%, and 65.80%, respectively. These variations may be attributed to genetic differences and the specific agro-climatic conditions in those regions.

Table 17. Influence of planting dates on NDF (%) of sorghum and sorghum-Sudan grass hybrids.

Cultivars	1st cut		Mean	2nd cut		Mean	3rd cut		Mean
	31st March	29th April		31st March	29th April		31st March	29th April	
Sorgo Sweet (USA)	50.31 cd	59.50 bc	55.00 B	42.00 e	60.61 bc	51.31 B	44.66	54.00	49.62
SS-1000 (South Africa)	48.66 de	58 bcd	53.33 B	47.61 cd	56.62 bc	52.17 B	45.00	56.00	50.81
Jumbo (Australia)	45.00 e	60.31 bc	52.61 B	43.00 de	57.33 bc	50.14 B	42.33	54.00	48.50
Sorghum-2011 (Pakistan)	68 ab	68.66 a	68.39 A	61.66 ab	69.00 a	65.32 A	---------	---------	------
Mean	53.00	61.67		48.58	60.90		44.00 B	55.00 A	

3.9. Acid Detergent Fibre (ADF %)

The ANOVA analysis for acid detergent fiber (ADF) percentage across the three cuts revealed that the planting date was non-significant (NS) in the first cut, while both cultivars and their interactions were highly significant ($p < 0.01$) (**Table 18**). In the second cut, the planting date became significant ($p < 0.05$), while the cultivars remained highly significant. In the third cut, the planting date was significant ($p < 0.05$), cultivars were NS, and the interaction was highly significant ($p < 0.01$).

In the treatment means comparison (**Table 19**), Jumbo consistently produced the lowest ADF percentages across all cuts, with values of 26.62%, 25.83%, and 25.00% for the first, second, and third cuts, respectively. In contrast, Sorghum-2011 had the highest ADF percentages, measuring 33.82%, 32.33%, no cut, for the three cuts. The 29th April planting produced an ADF of 28%, while the 31st March planting showed a significantly lower ADF of 23%. Overall, Jumbo exhibited the lowest ADF levels consistently across all cuts, while Sorghum-2011 had the highest ADF levels. Furthermore, the 31st March planting consistently resulted in lower ADF levels compared to the 29th April planting.

Table 18. Analysis of variance (ANOVA) for ADF (%).

		1st cut	2nd cut	3rd cut
SOV	**DF**	**F-ratio**	**F-ratio**	**F-ratio**
Replication	2			
Planting dates	1	2.30^{NS}	18.11^{*}	20.16^{*}
Error Replication*Planting dates	2			
Cultivars	3	12.80^{**}	13.75^{**}	3.59^{NS}
Planting dates*Cultivars	3	4.85^{**}	5.05^{**}	7.41^{**}
Error Replication*Planting dates*Cultivars	12			
Total	23			

* = $p \leq 0.05$, ** = $p \leq 0.01$, NS = non-significant.

Table 19. Influence of planting dates on ADF (%) of sorghum and sorghum-Sudan grass hybrids.

Cultivars	**1st cut**		**Mean**	**2nd cut**		**Mean**	**3rd cut**		**Mean**
	31st March	**29th April**		**31st March**	**29th April**		**31st March**	**29th April**	
Sorgo Sweet (USA)	25.31 cd	30.00 abc	27.00 BC	23.33 c	29.31 ab	26.33 B	23.61 bc	28.31 b	26.00
SS-1000 (South Africa)	27 bcd	32.30 ab	29.85 B	24.33 c	31.00 a	27.66 B	22.33 c	30.68 a	27.00
Jumbo (Australia)	28.00 abc	25.33 d	26.62 C	26.00 bc	25.66 c	25.83 B	23.00 bc	26.00 bc	24.83
Pak-Sudex (Pakistan)	34.00 a	33.66 a	33.82 A	32.00 a	32.66 a	32.33 A	---------	---------	-------
Mean	28.66	30.41		29.62	26.40		23.00 B	28.00 A	

The optimal ranges for NDF and ADF in livestock nutrition are 30% - 50% and 20% - 35%, respectively. NDF and ADF concentrations in sorghum are primarily impacted by the maturity stage at harvest. As sorghum matures, both NDF and ADF levels tend to increase [50]. However, the genetic make-up of sorghum plays a more significant role in determining fiber composition than environmental factors such as planting date [51] [52]. The values in the present study are comparatively lower than those reported by Carmi *et al.* [47], Colombo *et al.* [48], and Singh and Shukla [49], who found 62.80%, 62.60%, and 65.80%, respectively. Meanwhile, the mean ADF content recorded in the study ranged from 23.00% to 33.82%, which was lower than the values of 47.50% and 37.10% reported by Singh *et al.* [53] and Colombo *et al.* [48], respectively. This difference could be attributed to variations in cultivar and the stages of maturity of the samples used in this study.

4. Conclusions

The selection of right cultivars is vital for optimizing growth performance and overall productivity in sorghum and sorghum × Sudan grass hybrids (SSH). In this study conducted during the Kharif season of 2023, the influence of different planting dates and hybrid cultivars were evaluated to determine the best combinations for improved growth and fodder quality. Among the cultivars tested, SS-1000 consistently outperformed others, demonstrating superior growth characteristics such as greater leaf count, plant height, number of tillers, and green fodder yield. This hybrid also maintained the lowest levels of hydrocyanic acid, ensuring its safety for livestock.

The 31st March planting date, coupled with SS-1000, resulted in optimal plant development, higher crude protein content, and superior nutritional quality. In contrast, sorghum-2011, while showing lower overall performance, had higher levels of neutral detergent fiber (NDF) and acid detergent fiber (ADF), which could reduce fodder palatability and digestibility. These findings highlight the importance of hybrids selection, with SS-1000 being a standout for both growth and nutritional quality. The study underscores that early sowing and choosing high-performing cultivars like SS-1000 are vital for maximizing productivity and ensuring safe, nutritious fodder in response to climate variability.

Author Contributions

All authors have contributed to various aspects of the study, including conceptualization, writing, editing, and revisions.

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Conflicts of Interest

The authors declare that they are entirely free from any financial or ties that may have influenced the results presented in this work.

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