Research Article

Response of Sweet Sorghum Varieties to Different Fertilizer Doses for Sugar Recovery and Biomass Production Under Irrigated Conditions of Dera Ismail Khan

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Abstract | A field study was conducted in the Agronomic Research Area, Faculty of Agriculture, Gomal University, D.I. Khan to observe the effect of different fertilizer doses on the yield, biomass and the response of different cultivars of sweet sorghum, during the Kharif season (2015–16). The study was carried out using a split-plot layout and a randomized complete block design (RCBD). The cultivars of sweet sorghum were chosen for the main plots, while fertilizer doses were distributed in the sub-plots. Fourteen parameters were monitored throughout the study. According to the data that was analyzed, the research's variables had a substantial impact on leaf area index (LAI), green fodder yield (t ha), plant height (cm), net photosynthesis rate (u mole m-^{2} sec^{-1}), crop growth rate (g cm^{2} day^{1}), (%), brix (%), bagasse (%), purity (%), reducing sugars and pol (%). Though, there was not a noticeable impact on the amount of chlorophyll (u g cm^{3}) or the number of leaves on the plant. The most significant interaction between the Sudan grass hybrid and fertilizer increased the crop growth rate (16.43 g day), leaf area index (5.01), net photosynthesis rate (66.07 mole m^{2} sec"), green fodder yield (109.99 t ha"), reducing sugars% (2.47), brix% (13.50), and pol% (8.11). Based on the research results, it has been found that Sudan grass hybrids fertilizer using NPK @ (150:120:100 kg ha") attained better green fodder production while the sugar and ethanol generating parameters performed best with NPK @ 100:80:60: kg ha".

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Introduction

In terms of climate, Dera Ismail Khan is categorized as an arid to semi-arid region of Pakistan. Low and infrequent rainfall, high evaporation during the Kharif season (crops that are planted in summer and harvested in winter), and clay-like soil are characteristics of this region. So, this climate is suitable for cultivation of sorghum (Hussain *et al*., 2021). *Sorghum bicolor* L. Moench, sometimes known as sweet sorghum, is a versatile crop with several uses, including as a source of energy and syrup. It has the potential to produce ethanol from its raw materials because of its high biomass production, quick drying time, low water requirement, and wide range of adaptability (Reddy *et al*., 2005). It is mostly cultivated for its syrup, also referred to as black honey. It is projected that sorghum syrup will soon become one of the primary sources for syrup manufacturing if the quality of the syrup improves. Osman *et al*. (2005) and Mohamed *et al*. (2006) claimed that good sorghum syrup has a characteristic flavor and is light in color and mild. As a result, this increases the amount of cane yield available for sugar production and reduces the enormous disparity between sugar output and consumption, which was at almost 1.10 million tons. Numerous factors have significant impact on the quality and productivity of sweet sorghum. The primary critical decision in sweet sorghum is variety assortment. Sorghum cultivars differ significantly in terms of stalk height, diameter, number of internodes, producing syrup, yield, and its component parts, according to (Chawdhury and Rahman, 1990; Mohamed *et al*., 2006).

Gnansounou *et al*. (2005) claimed that sweet sorghum has higher photosynthetic competency, adaptability to moderate area, and famine endurance. Following crop harvest, the extraction and processing of juice should be necessary (Gnansounou *et al*., 2005; Kundiyana, 2006; Bridgers *et al*., 2011). According to Tamang *et al*. (2011), there were no appreciable effects on the yield of sweet sorghum from the use of nitrogen fertilizer at 0 to 168 kg ha^{-1}. Compared to a crop that wasn't fertilized, the crop treated with fertilizer increased yield from 23 to 43%. More nitrogen application slightly reduced the Brix %. Barbanti *et al*. (2006) indicated that there is no distinction in yield among non-fertilized crop and the one treated with 60 kg nitrogen ha^{-1}, on the other hand the nitrogen rate @ 120 kg ha^{-1} reduced the yield.

Sawargaonkar *et al*. (2013) examined various nitrogen rates and discovered a significant impact of nitrogenous fertilizer on sweet sorghum yield. They further investigated various nitrogen concentrations and found that impacts were substantial at a level of N @ 100 kg ha^{-1}. According to Mohamed *et al*. (2006), total profit gains increased up to 90 kg nitrogen each year. With the treatment of various nitrogen concentrations ranging from 45 to 180 kg ha^{-1}, sweet sorghum has no discernible effect on yield (Erickson *et al*., 2012). The biological yield and sugar percentage of the Sweet Sorghum crop are essential components for animal feed as well as the need of the sugar production sectors. Biomass and yield can be increased by applying the right amount of fertilizer (Johnston, 2000; Rego *et al*., 2003). According to (Stales and Inze, 2001; Zhao *et al*., 2005; Saraswathy *et al*., 2007), nitrogenous fertilizers significantly influence crop development and overall biological yield.

Potassium contributes to the translocation and accumulation of sucrose in plant storage tissues. Potassium fertilizer raises the sucrose percentage without noticeably lowering the purity percentage. Sweet sorghum crop yield is also increased by potassium fertilizer (Pholsen and Sornsungnoen, 2004). For optimal conversion of solar energy (sunlight) into chemical energy during photosynthesis, potassium fertilizer is necessary (Mengel and Kirkby, 2001).

Various Sweet Sorghum cultivars differ in the amount of sugar (%) in their juice (Almodares *et al*., 1994). More adaptability can be found in sweet sorghum (Reddy *et al*., 2005). It performed well in temperate and sub-tropical climates and need less water (Tesso *et al*., 2005). Sweet sorghum is a drought-resistant crop. Sweet sorghum has the best tolerance for salt, water lodging, and yield, according to (Almodares *et al*., 2007, 2008). Sweet sorghum is a long-day crop (C4) that photosynthesize rapidly. As a result, sweet sorghum plays a crucial function in raising agricultural productivity and giving animals the best possible feed (Fazaeli *et al*., 2006). There is a lack of information in the literature about NPK management in sweet sorghum.

The objectives of the current Sweet Sorghum research were designed keeping in view the aforementioned advantages. To assess the available varieties for sugar recovery percentages by various NPK management in the irrigated environment of D. I. Khan KP, Pakistan.

Materials and Methods

In 2015, the study was conducted at the Gomal University Agriculture Faculty Research Centre in D.I. Khan, Khyber Pakhtunkhwa.

Experimental design

Three replications of a split plot, RCBD design were used to set up the experiment. The area was ploughed with primary and secondary tillage tools for better seedbed preparation. Each plot was maintained to be 1.8 m 5 m (6 lines) in size, with a 30 cm between each row and a 20 cm between each plant. Three nitrogen fertilizer dosages (0:100:150 kg ha^{-1}), three phosphorus fertilizer dosages (0:80:120 kg ha^{-1}), and three potassium fertilizer dosages (0:60:100 kg ha^{-1}) were divided into a factorial grouping and assigned to sub plots. Six varieties of sweet sorghum were kept in the main plot: Sudan Grass, Proline, Bhagdar, Frontline, White Desi Sorghum, and Red Desi Sorghum.

Here are the specific treatments:
Main plots (varieties): V1 = Proline; V2 = Frontline; V3 = Bhagdar; V4 = Sudan Grass; V5 = White Desi Sorghum; V6 =Red Desi Sorghum.

Sub-plot (fertilizer levels): F0 = Control (No Fertilizer was applied); F1 = N: P: K (100:80:60 kg ha^{-1}); F2 = N: P: K (150:120:100 kg ha^{-1}).

The crop was irrigated three times. First irrigation was applied 25 days after sowing, 2^{nd} irrigation was applied 45 days after sowing while the last irrigation was done 65 days after sowing. The amount of irrigation was applied in usual amount as given by a single irrigation (4 acre inches) by canal water.

Months	Temperature °C		Rainfall (mm)
	Minimum	Maximum	
July	26	42	85
August	35	47	78
September	32	43	41
October	27	38	46

Sampling

Three treatments from each replicate were harvested daily from each sub-plot and the agronomic parameters were observed. Immediately the samples were taken to the laboratory of Al Moiz Industries Limited, Dera Ismail Khan. Plant height, leaf area index, number of leaf per plant, green fodder yield, net photosynthetic rate, harvest index, crop growth rate, benefit cost ratio, reducing sugars, brix (%) of juice, Pol (%), Purity (%), bagasse (%) was recorded.

Where; Purity % is the actual sucrose contents present in a juice.

The formula is Purity% = (Pol/brix)× 100

Pol is "Pol% is sucrose contents of a juice measured by polarimeter. "It is the reading of polarimeter when plane polarized light is passed through a solution. The solution containing optically active substances (sugars), rotates the symmetry of plane polarized light. Since these are three sugars in a sorghum juice (glucose, fructose and sucrose). Glucose and fructose are equimolar and counter the rotatability effect; therefore, pol is the net result of sucrose content.

Table 1: *Plant height (cm) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	297.15 c	312.73 b	316.07 a	308.65 a
V_2 (Frontline)	242.14 l	261.82 i	289.22 d	264.39 d
V_3 (Bagdar)	257.05 j	266.24 h	270.37 g	264.55 d
V_4 (Sudan grass)	252.09 k	311.97 b	312.71 b	292.25 b
V_5 (White desi)	216.40 n	229.22 m	229.53 m	225.05 e
V_6 (Red desi)	275.50 f	282.31 e	283.14 e	280.32 c
Means	256.72 c	277.38 b	283.50 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Non-significant results. $LSD_{0.05}$. For varieties = 1.7296; For fertilizer doses = 1.3590; For interaction = 3.2198

Results and Discussion

Plant height (cm)

Significant findings for several sweet sorghum cultivars, fertilizer levels, and their interactions were shown by the data in Table 1. Among different interactions, tallest plant (316.07 cm) were recorded in Proline by applying NPK @ (150:120:100 kg ha^{-1}), pursued by (100:80:60 kg ha^{-1}) fertilizer dose in the same variety, and also in Sudan Grass with (150:120:100 kg ha^{-1}) and (100:80:60 kg ha^{-1}) fertilizer dose by giving statistically at par heights 312.73, 312.71 and 311.97cm, respectively. White Desi sorghum, which received no fertilizer application, had the smallest plants (216.40 cm). Following that, the same variety received fertilizer doses of (100:80:60 kg ha^{-1}) and (150:120:100 kg ha^{-1}) at statistically par heights of 229.22 and 229.53 cm, respectively. The tallest plant in Proline and Sudan Grass with maximal fertilizer dose (150:120:100 kg ha^{-1}) might be due to balance nutrients supply with higher genetic potential of sweet sorghum varieties. Regarding plant height the results obtained by Afzal *et al*. (2013) also support our findings who reported the conclusive response of N-fertilizer on plant height as compared to non-application of N-fertilizer (control).

Leaf area index (LAI) (30 days of sowing)

Leaves are described as photosynthetic source of crops. Photosynthesis is a physiological phenomenon by which light energy is harvested through leaves and food of plants manufactured. Leaves area and its index are a source to uphold the source sink relationship and establishing the green biomass. The data shown in Table 2 depicted that sweet sorghum varieties, fertilizer doses and their interaction were found significant. The largest leaf area index (3.3167) was recorded in Sudan Grass hybrid by applying maximum fertilizer dose NPK @ (150:120:100 kg ha^{-1}), followed by the same variety with (100:80:60 kg ha^{-1}) fertilizer dose by giving statistically at par LAI of (3.1267). Whereas the minimum LAI of 1.3153was observed in Bagdar variety receiving no fertilizer (control), followed by the variety Frontline receiving no NPK fertilizer dose (control) by providing statistically at par LAI of 1.3227. The largest leaf area index of Sudan Grass by applying maximum fertilizer dose (150:120:100 kg ha^{-1}) might be due to abundant and balanced nutrients supply to plant and also the genetic potential of this variety for producing largest and wider leaves early in growth seasons. The results obtained by Afzal *et al*. (2013) and Kumar *et al*. (2012) also support our finding who reported that N-fertilizer play positive effect on leaf area index as compare to no fertilizer application.

Leaf area index (30 days after first leaf area index)

The data shown in Table 3 indicated that sweet sorghum varieties, fertilizer levels and their interaction were found significant. The largest leaf area index 5.0133 was found in Sudan Grass hybrid by applying the maximum fertilizer does NPK @ (150:120:100 kg ha^{-1}), followed by the same variety with applying fertilizer dose (100:80:60 kg ha^{-1}) by giving leaf area index of 4.183 and also in Frontline and Proline hybrid with fertilizer doses of (150:120:100 kg ha^{-1}) and (100:80:60 kg ha^{-1}) by producing LAI of 3.920, 3.910 and 3.810 respectively. While the smallest leaf area index of 1.770 was found in Red Desi sorghum receiving no fertilizer application, followed by the White Desi sorghum which had also received no fertilizer, by providing statistically at par LAI of 2.0867. The largest LAI might be due to maximum fertilizer dose which supplied balanced nutrients requirement to the hybrid sweet sorghum varieties that utilized it for their vegetative development during early growth period. Naseer *et al*. (2017) also stressed on significance of leaf area index in photosynthesis and conversion of photosynthates into sugar. Similarly, Moghimi and Eman (2015) checked the impact of different N level on sorghum cultivars. The outcome depicted that leaf area index increased with increment in each nitrogen level.

Table 2: *Leaf area index (30 days of sowing) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	1.341gh	1.556 efgh	1.8710 cd	1.5894b
V_2 (Frontline)	1.3227 h	01.710cdef	1.9037 bc	1.6454b
V_3 (Bagdar)	1.3153 h	1.811 cde	1.917 bc	1.6812b
V_4 (Sudan grass)	2.2067 b	3.1267 a	3.3167 a	2.8833a
V_5 (White desi)	1.458 fgh	1.499efgh	1.467 fgh	1.4747b
V_6 (Red desi)	1.465 fgh	1.663cdefg	1.563 defgh	1.5640b
Means	1.5182 b	1.8944 a	2.0064 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results; $LSD_{0.05}$; For varieties = 0.2284; For fertilizer doses = 0.1199; For interaction = 0.3309.

Table 3: *Leaf area index (30 days after first leaf area index) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	2.810 g	3.810cd	3.910cd	3.51b
V_2 (Frontline)	2.2267h	3.150ef	3.920bc	3.098 d
V_3 (Bagdar)	2.646g	3.240e	3.910cd	3.265 c
V_4 (Sudan grass)	3.646d	4.183b	5.0133a	4.281 a
V_5 (White desi)	2.0867h	2.9067fg	2.8167g	2.603 e
V_6 (Red desi)	1.770i	2.7033g	2.7367g	2.403 f
Means	2.531 c	3.332 b	3.717 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS =Nonsignificant results. $LSD_{0.05}$; For varieties = 0.1556; For fertilizer doses = 0.1099; For interaction = 0.2691

Number of leaf plant^{-1}

The data in Table 4 indicated that sweet sorghum varieties, fertilizer doses were found significant while their interactions were non-significant. The maximum numbers of leaves per plant were recorded in Frontline, Sudan grass and Proline hybrid which produced 9.39, 9.27 and 9.0 and were statistically at par, followed by varieties Bagdar and Red Desi sorghum which produced 7.78 and 8.42 leaves plant^{-1} that were also statistically at par. Data regarding fertilizer dose also showed decreasing trend with decreasing fertilizer doses. The maximal number of leaves in each plant 9.19 were noted in NPK @ (150:120:100 kg ha^{-1}), followed by (100:80:60 kg ha^{-1}) which produced 8.84 leaves plant^{-1}. While the minimum leaves plant^{-1} of 7.79 were recorded in control fertilizer treatment. The results obtained by Afzal *et al*. (2013) also supported our finding who reported that number of leaf plant^{-1} depends upon the adaptability and as well as genetic character of the varieties. But in our case no. of leaves significantly higher at maximum NPK level (F2). This result was expected with high balance nutrient management to better access by genotypes to sunlight and moisture. These findings are in accordance with Mahdi *et al*. (2011). According to them, this result may be attributed to ample availability of physical factors like nutrients, moisture and light.

Table 4: *Number of leaves plant^{-1} of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	8.567	8.900	9.533	9.0 ab
V_2 (Frontline)	8.467	9.667	10.033	9.3889 a
V_3 (Bagdar)	7.133	7.933	8.267	7.7778 c
V_4 (Sudan grass)	7.900	9.733	10.167	9.2667 a
V_5 (White desi)	7.000	8.100	8.267	7.7889 c
V_6 (Red desi)	7.667	8.733	8.867	8.4222bc
Means	7.7889c	8.8444 b	9.1889 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$. For varieties = 0.7295; For fertilizer doses = 0.3057; For interaction = NS

Green fodder yield (tha^{-1})

Balance nutrient availability and manure application are the key factors that affect the green biomass of sorghum. The data with respect to green fodder yield drawn in Table 5 indicated that varieties of sweet sorghum, fertilizer doses and their interaction were found significant. The maximum green fodder yield 109.99 tha^{-1} was recorded in Sudan grass hybrid by applying maximum fertilizer dosage of NPK @ (150:120:100 kg ha^{-1}), followed by the same variety by applying optimum fertilizer doses (100:80:60 kg ha^{-1}) and in Proline hybrid with (150:120:100 kg ha^{-1}) fertilizer dose by providing green fodder yield of 103.70 and 103.61 tha^{-1}, respectively. While the minimum green fodder yield 49.40 tha^{-1} was recorded in White Desi sorghum receiving no fertilizer application, followed by the same variety with the utilization of (100:80:60 kg ha^{-1}) fertilizer dose and in Red Desi sorghum with no fertilizer application (control), by providing green fodder yield of 49.72 and 50.20 tha^{-1}, respectively. The maximum green fodder yield in Sudan grass hybrid along with maximum application of fertilizer (150:120:100kg ha^{-1}) is due to genetic potential of that hybrid and their adaptability to the given environment of D.I. Khan with its maximum utilization of nutrients which resulted in maximum green fodder yield among all the other varieties. The similar effect of nitrogen fertilizers and genotypes on GFY in Sweet Sorghum was also revealed by other workers (Almodares *et al*., 2009; Miri and Rana, 2014). Similar findings are reported by Mahdi *et al*. (2011) who determined significant green biomass by application of high dose of nitrogen.

Table 5: *Green fodder yield (t ha^{-1}) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	81.60 h	87.17 e	103.61 b	90.792 b
V_2 (Frontline)	82.41 g	84.38 f	100.28 c	89.023 c
V_3 (Bagdar)	52.65 l	82.54 g	90.49 d	75.229 d
V_4 (Sudan grass)	64.55 k	103.70 b	109.99 a	92.746 a
V_5 (White desi)	49.40 n	49.72 mn	52.47 l	50.531f
V_6 (Red desi)	50.20 m	75.82 j	78.62 i	68.213 e
Means	63.469 c	80.554 b	89.244 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Non-significant results. $LSD_{0.05}$; For varieties = 0.2831; For fertilizer doses = 0.2063; For interaction = 0.5000

Net photosynthetic rate (µ mole m^{-2} sec^{-1})

Manuring, light, moisture and cultivars are the principal units which affect the photosynthesis of any crop. The figures written in Table 6 indicated that sweet sorghum varieties, fertilizer doses and their interaction were found significant. Regarding photosynthesis rate the maximum photosynthesis rate 66.067 were recorded in Sudan Grass hybrid

Table 6: *Net photosynthesis rate (µ mole m^{-2} sec^{-1}) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	65.167 a	62.333 abc	52.167 fg	59.889 a
V_2 (Frontline)	63.533 ab	60.433 abcde	52.067 fg	58.678 a
V_3 (Bagdar)	56.233 cdef	60.667 abcde	61.133abcd	59.344 a
V_4 (Sudan grass)	57.100 bcdef	63.333 ab	66.067 a	62.167 a
V_5 (White desi)	46.533 g	54.267 ef	53.300 f	51.367 b
V_6 (Red desi)	33.267 h	55.433 def	38.733 h	42.478 c
Means	53.639 b	59.411 a	53.911 b	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$; For varieties = 4.4429; For fertilizer doses = 2.3810; For interaction = 6.5080

by applying maximum nourishment dose NPK @ (150:120:100kg ha^{-1}), followed by the Proline hybrid with no fertilizer application and also in Sudan Grass by applying optimum fertilizer dose of (100:80:60kg ha^{-1}) providing net photosynthesis rate of 65.167 and 63.333, respectively. While the minimum photosynthesis rate of 33.267 was recorded in Red Desi sorghum without fertilizer application, followed by the same variety with operation of (150:120:100 kg ha^{-1}) fertilizer providing photosynthesis rate of 38.733. The maximum photosynthesis rate in Sudan Grass hybrid with maximum nourishment dose (150:120:100 kg ha^{-1}) was due to balanced nutrient supply which helps plant to increase their photosynthesis rate and also there must be some genetic makeup of hybrid variety having higher photosynthesis rate capability. Net Photosynthesis rate was significant affected by nitrogen fertilizer application on Sweet Sorghum (Curtis *et al*., 2015). Photosynthesis also based on plant canopy which is controlled by genetic makeup and interacted with ecosystem to which crops are subjected during the growth and development (Mahdi *et al*., 2011). Reduction is net photosynthesis rate at F2 (high dose) may be due canopy effect and increased in competition for light and air. Another reason behind this result reduction in cholorophyll content and loss of metabolic energy related to adaptations of climate by different cultivars as reported by Hadi and Firoozabadi (2022).

Harvest index (HI)

The figures concerning harvest index showed in Table 7 depicted that sweet sorghum varieties, fertilizer doses and their interaction were found significant. The maximum harvest index (HI) 94.490 were recorded in Proline hybrid by applying no fertilizer, followed by same variety with NPK @ (100:80:60 kg ha^{-1}) fertilizer dose and also in Sudan Grass hybrid by applying maximum level of fertilizer (150:120:100kg ha^{-1}) and (100:80:60kg ha^{-1}) by providing statistically at par HI of 87.453, 87.370 and 87.113 respectively. While the minimum harvest index 72.193 was recorded in White Desi sorghum by applying maximum nourishment dose (150:120:100 kg ha^{-1}), followed by the Red Desi sorghum without fertilizer application by providing HI of 81.530. The maximum harvest index in Proline hybrid without fertilizer application showed that there may be no effect of fertilizer on the rate of harvest index. But due to the genetically more efficiency of Proline hybrid increases the harvest index. The effect of nitrogen fertilizers on Harvest Index in Sweet Sorghum crop was also described by Zand *et al*. (2014).

Table 7: *Harvest index (HI) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	94.490 a	87.453 b	85.323 de	89.089a
V_2 (Frontline)	82.383 f	85.360 de	85.880 cd	84.541d
V_3 (Bagdar)	87.260 b	85.667 cd	84.633 e	85.853c
V_4 (Sudan grass)	86.587 bc	87.113 b	87.370 b	87.023b
V_5 (White desi)	84.377 e	85.100 de	72.193 g	80.557e
V_6 (Red desi)	81.530 f	85.360 de	87.207 b	84.699d
Means	86.104 a	86.009 a	83.768 b	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Non-significant results. $LSD_{0.05}$; For varieties = 0.6051; For fertilizer doses = 0.3954; For interaction = 0.9950

Crop growth rate (CGR) (g m^{-2} day^{-1})

Growth is the basic features of living things. In plants, growth is determined in terms of increment in green biomass, dry weight analysis and leaves area. The results pertaining to CGR presented in Table 8 showed that different sweet sorghum varieties, fertilizer doses and their interactions were found significant. The higher crop growth rate (CGR) 16.433 (gm^{-2} day^{-1}) was recorded in Sudan Grass hybrid by applying maximum nourishment dose NPK @ (150:120:100kg ha^{-1}), followed by the Proline hybrid with upper limit of fertilizer dose (150:120:100kg ha^{-1}), by providing statistically at par CGR of 12.759 (g m^{-2} day^{-1}). While the least rate of CGR 3.585 (g m^{-2} day^{-1}) was recorded in Frontline without fertilizer application, followed by Red Desi sorghum by applying no fertilizer application (control), providing CGR of 5.019 (g m^{-2} day^{-1}). The higher CGR in Sudan Grass with maximum supply of inorganic fertilizer dose NPK @ (150:120:100 kg ha^{-1}) was due to proper and balance nutrient supply at proper time and also there must be the adaptability of particular Sudan Grass hybrid in that location which utilized more nutrients during the growth period of plant than the other varieties. Ababyomic (2016) recorded same results by accomplished distinct nitrogen levels. He found by increment in nitrogen, increment in growth rate is recorded.

Table 8: *Crop growth rate (CGR) (g m^{-2} day^{-1}) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	8.373 ghi	11.378 cd	12.759 b	10.837b
V_2 (Frontline)	3.585 n	6.773 jk	10.880 de	7.080 c
V_3 (Bagdar)	8.166 hij	9.618 efg	12.658 bc	10.147b
V_4 (Sudan grass)	8.747 fgh	12.717 bc	16.433 a	12.632a
V_5 (White desi)	5.256 lm	7.241 ijk	10.062 def	7.520c
V_6 (Red desi)	5.019 mn	6.127 kl	8.427 ghi	6.524c
Means	6.524 c	8.976 b	11.870 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$; For varieties = 1.3367; For fertilizer doses = 0.3327; For interaction = 1.4924

Benefit cost ratio (BCR)

The data regarding benefit cost ratio shown in Table 9 depicted that sweet sorghum varieties, fertilizer doses and their interactions were found significant. The maximum benefit cost ratio (BCR) of 3.6625 were recorded in Frontline hybrid by applying no fertilizer, followed by the hybrid Proline without fertilizer application (control) and also followed by Sudan Grass hybrid by applying optimum level of fertilizer NPK @ (100:80:60 kg ha^{-1}) by providing statistically at par BCR of 3.6267and 3.0411, respectively. While the minimum benefit cost ratio of 1.2893 was recorded in White desi sorghum by applying maximum dose of fertilizer (150:120:100 kg ha^{-1}), followed by the same variety by applying optimum fertilizer application (120:80:60 kg ha^{-1}) by providing BCR of 1.4580. The maximum BCR in Frontline hybrid without fertilizer application (control) showed that the cost of production without fertilizer application was minimum which directly increased the BCR of the crop while the crop with maximum fertilizer application increased the cost of production but at the same time also increased the biological yield of that crop. The results obtained by Mahdi *et al.* (2011) also supported our finding who reported the effect of nitrogen fertilizer on the benefit cost ratio (BCR).

Table 9: *Benefit Cost Ratio (BCR) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	3.6267 b	2.5563 f	2.5456 f	2.9095 a
V_2 (Frontline)	3.6625 a	2.4745 g	2.4640 g	2.8670 b
V_3 (Bagdar)	2.3401 i	2.4205 h	2.2234 jk	2.3280 c
V_4 (Sudan grass)	2.8689 d	3.0411 c	2.7024 e	2.8708 b
V_5 (White desi)	2.1957 k	1.4580 m	1.2893 n	1.6476 e
V_6 (Red desi)	2.2311 j	2.2234 jk	1.9318 l	2.1288 d
Means	2.8208 a	2.3623 b	2.1927 c	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS=Nonsignificant results. $LSD_{0.05}$; For varieties = 8.727E-03; For fertilizer doses = 0.0167; For interaction = 0.0346

Reducing sugars (%)

The data revealed in Table 10 indicated that on reducing sugar (R.S) sweet sorghum varieties, fertilizer levels and their interaction were found to be significant ($p \leq 0.05$). The maximum amount of R.S. (2.470%) was recorded in Sudan Grass and Frontline hybrid by applying the optimum fertilizer dose of NPK @ (100:80:60 kg ha^{-1}). Reducing sugars content of the Proline, Bagdar and Red Desi were recorded to be 2.373, 2.373 and 2.373% while applying the fertilizer dose of (100:80:60 kg ha^{-1}) respectively. The White Desi and Red Desi sorghum were found to be

R.S. of 1.670 and 1.730% while using fertilizer dose of (150:120:100 kg ha^{-1}) appropriately. The Red Desi sorghum possessed minimum R.S. of 1.430% with no fertilizer applied (control). Reducing sugar contents were found to be affected by variety as observed by correlation coefficient (R^2=0.552) while R.S. were unaffected by fertilizers (R^2=0.023). The similar response of nitrogenous and potash fertilizers on R.S. in Sweet Sorghum juice was also proclaimed by other workers (Almodares *et al*., 2008; Sheikh *et al*., 2011).

Table 10: *Reducing sugar (%) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	2.160 d	2.370 b	2.210 c	2.246 b
V_2 (Frontline)	2.240 c	2.470 a	1.870 g	2.193 c
V_3 (Bagdar)	2.003 f	2.336 b	2.066 e	2.135 d
V_4 (Sudan grass)	2.370 b	2.470 a	2.140 d	2.326 a
V_5 (White desi)	1.870 g	2.030 ef	1.670 i	1.856 e
V_6 (Red desi)	1.430 j	2.370 b	1.730 h	1.843 e
Means	2.012 b	2.341 a	1.947 c	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$; For varieties = 0.0496; For fertilizer doses = 7.490E-03; For interaction = 0.0518

Table 11: *Brix % of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	11.20 e	9.00 m	9.15 l	9.78 e
V_2 (Frontline)	8.10 n	10.90 g	10.45 j	9.81 e
V_3 (Bagdar)	11.15 e	11.60 d	11.00 f	11.25 b
V_4 (Sudan grass)	10.10 k	12.38 c	10.70 i	11.06 c
V_5 (White desi)	12.75 b	12.90 a	12.85 a	12.83 a
V_6 (Red desi)	11.15 e	10.90 g	10.80 h	10.95 d
Means	10.74 c	11.28 a	10.82 b	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$; For varieties = 0.0541; For fertilizer doses = 0.0328; For interaction = 0.0849

Brix % of juice

Sweet sorghum varieties, fertilizer doses and their interaction were found significant ($p \leq 0.05$) with report to brix profile (Table 11). The maximum Brix % of 12.90 was recorded in White Desi sorghum by applying optimum fertilizer dose of NPK @ (100:80:60: kg ha^{-1}). Brix % of White Desi was also recorded to be 12.85 and 12.75 % while applying the fertilizer dose of (150:120:100: kg ha^{-1}) and with no fertilizer (control) appropriately. The cultivar Proline was found to be 9.00% of Brix while using fertilizer dose (100:80:60: kg ha^{-1}). The Frontline hybrid possessed minimum Brix % of 8.10 having no fertilizer application (control). Brix % of juice were found to be affected by variety as observed by correlation coefficient (R^2=0.490) while the said parameter was unaffected by fertilizers (R^2=0.020). The similar effect of fertilizer and variety on Brix % in sweet sorghum juice was also described by some researchers (Almodares *et al*., 2007, 2008; Miri and Rana, 2014).

Table 12: *Pol % of Juice of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2 N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	6.00 g	3.26 j	3.28 j	4.18 d
V_2 (Frontline)	2.84 k	3.52 i	5.51 h	3.95 e
V_3 (Bagdar)	6.26 f	7.10 e	5.43 h	6.26 c
V_4 (Sudan grass)	5.53 h	8.38 a	6.37 f	6.76 b
V_5 (White desi)	7.69 c	7.45 d	8.04 b	7.72 a
V_6 (Red desi)	6.20 fg	7.16 e	7.18 e	6.84 b
Means	5.75 c	6.14 a	5.96 b	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Non-significant results. $LSD_{0.05}$; For varieties = 0.1333; For fertilizer doses = 0.0833; For interaction = 0.2133

Pol %

The data regarding Pol % of juice shown in Table 12 depicted that sweet sorghum varieties, fertilizer doses and their interaction were found significant ($p \leq 0.05$). The maximum Pol % of 8.38 was recorded in Sudan Grass hybrid by applying optimum fertilizer dose of NPK @ (120:80:60 kg ha^{-1}). Pol % of the White Desi sorghum was recorded to 8.04 and 7.69 % while applying the fertilizer doses of (150:120:100 kg ha^{-1}) and with no fertilizer (control) respectively. Pol % profile of Frontline and Proline hybrid were found to be 3.52 and 3.26 while using fertilizer dose of (120:80:60 kg ha^{-1}) respectively. The hybrid Frontline possessed least Pol % of 2.84 without fertilizer application (control). There was a maximum correlation between Pol % of juice and varieties of sweet sorghum by giving correlation coefficient (R^2=0.763) and also affected by optimum fertilizer dose (R^2 = 0.996). The similar effect of fertilizer and varieties on Pol % in Sweet Sorghum juice was also expressed by Robert *et al*. (2007).

Table 13: *Purity (%) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	53.64 gh	36.26 j	35.91 j	41.94 d
V_2 (Frontline)	35.25 j	32.30 k	52.92 h	40.16 e
V_3 (Bagdar)	56.29 ef	61.39 bc	49.54 i	55.74 c
V_4 (Sudan grass)	54.93 fgh	67.71 a	59.70 cd	60.78 b
V_5 (White desi)	60.43 c	57.82 de	62.74 b	60.33 b
V_6 (Red desi)	55.79 efg	65.86 a	66.76 a	62.81 a
Means	52.72 c	53.56 b	54.59 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$; For varieties = 1.7652; For fertilizer doses = 0.8016; For interaction = 2.3827

Purity (%) (Actual sucrose contents present in a juice)

The data regarding purity (%) revealed in Table 13 depicted that sweet sorghum varieties, fertilizer doses and their interaction were found significant ($p \leq 0.05$). The maximum purity % of 67.71 was recorded in Sudan Grass hybrid by applying optimum fertilizer dose of NPK @ (120:80:60 kg ha^{-1}). Purity % of Red Desi, White Desi and Bagdar were recorded to 66.76, 65.86, 62.74 and 61.39 % while applying the fertilizer dose of (120:80:60 kg ha^{-1}) and (150:120:100 kg ha^{-1}) respectively. Purity % profile of Frontline and Proline were found to be 35.25, 35.91 and 36.26 while with no fertilizer doses (control), (150:120:100 kg ha^{-1}) and (120:80:60 kg ha^{-1}), respectively. The Frontline possessed minimum Purity % of 32.30 having fertilizer dose of (120:80:60 kg ha^{-1}). Purity % were found to be affected by variety as observed by correlation coefficient (R^2=0.82) while Purity % were also affected by fertilizer (R^2=0.996). The similar effect of fertilizer and variety on Purity % in sweet sorghum juice was also narrated by (Robert *et al*., 2007; Almodares *et al*., 2009; Sheikh *et al*., 2011; Mahdi *et al*., 2011).

Bagasse (%)

The data regarding Bagasse (%) revealed in Table 14 depicted that sweet sorghum varieties, fertilizer doses and their interaction were found significant ($p \leq 0.05$). The maximum Baggasse (%) of 13.287 % was recorded in White Desi sorghum by applying fertilizer doses of NPK @ (150:120:100 kg ha^{-1}). Bagasse (%) of Red Desi, White Desi sorghum and Sudan Grass was recorded to 12.60, 11.697 and 11.220% while applying the fertilizer dosage of NPK @ (150:120:100 kg ha^{-1}) and without fertilizer application (control) respectively. The Proline hybrid possessed minimum Bagasse (%) of 8.310 having no fertilizer application (control). While the hybrid Sudan Grass also possessed lower Bagasse (%) 8.440 with no fertilizer application (Control). Bagasse (%) were found to be affected by variety as observed by correlation coefficient (R^2= 0.660) and also affected by fertilizers doses (R^2= 0.998). The similar effect of fertilizer and variety on Bagasse % (fiber) in sweet sorghum was also noted by Roland *et al*. (2012).

Table 14: *Bagasse (%) of different sweet sorghum varieties as affected by NPK levels during 2015-2016.*

Varieties	Fertilizer levels			Means
	F0 (Control)	F1 N:P:K (100:80:60 kg ha^{-1})	F_2N:P:K (150:120:100 kg ha^{-1})	
V_1 (Proline)	8.310 k	9.490 h	10.660 ef	9.487 e
V_2 (Frontline)	8.670 j	9.040 i	10.170 g	9.293 e
V_3 (Bagdar)	9.440 h	10.650 f	10.950 de	10.347 c
V_4 (Sudan grass)	8.440 jk	10.410 fg	11.220 d	10.023 d
V_5 (White desi)	11.697c	12.490 b	13.287 a	12.491 a
V_6 (Red desi)	10.200g	11.180 d	12.600 b	11.327 b
Means	9.459 c	10.543 b	11.481 a	

Non-similar letter(s) in rows and columns show significant at 5% probability level. NS= Nonsignificant results. $LSD_{0.05}$; For varieties = 0.2859; For fertilizer doses = 0.0624; For interaction = 0.3118

Table 15: Mean square values of *plant growth and biochemical attributes of different sweet sorghum varieties as affected by NPK levels.*

Source	df	Plant height (cm)	LAI (30 days of sowing)	LAI (30 days after first leaf area index)	Chlorophyll content (μ g cm^{-2}) (after 60 days of sowing)	Number of leaves plant^{-1}
Replicates	2	90.33	3.09805	3.35085	20.008	4.07574
Factor-A (Varieties)	5	7449.22***	2.55102***	4.08577***	47.848*	4.66563***
Error A	10	2.71	0.04727	0.02194	14.340	0.48241
Factor-B (Fertilizer doses)	2	3545.18***	1.17726***	6.59583***	370.828***	9.57852***
A x B	10	485.72***	0.13918**	0.16029***	1.641ns	0.24785*
Error B	24	3.90	0.03039	0.02551	2.709	0.19741
Total	53					

Table 16: Mean square values of *plant growth and biochemical attributes of different sweet sorghum varieties as affected by NPK levels.*

Source	df	Green fodder yield (t ha^{-1})	Net photosynthesis rate (μ mole m^{-2} sec^{-1})	Harvest index (HI)	Crop growth rate (CGR) (g m^{-2} day^{-1})	Benefit cost ratio (BCR)
Replicates	2	72.68	39.590	65.5082	30.320	0.07877
Factor-A (Varieties)	5	2448.41***	495.190***	73.9223***	53.634***	2.38230***
Error A	10	0.07	17.892	0.3319	1.620	0.00007
Factor-B (Fertilizer doses)	2	3095.41***	190.928***	31.4752***	128.863***	1.90059***
A x B	10	268.52***	118.690***	47.3792***	2.597***	0.31614***
Error B	24	0.09	11.978	0.3303	0.234	0.00059
Total	53					

Table 17: Mean square values of *plant growth and biochemical attributes of different sweet sorghum varieties as affected by NPK levels.*

Source	df	Reducing sugar (%)	Brix %	Pol %	Purity (%)	Bagasse (%)
Replicates	2	0.64623	18.1503	1.5445	91.717	16.0741
Factor-A (Varieties)	5	0.37431***	11.3307***	21.2809***	905.018***	13.2864***
Error A	10	0.00223	0.0027	0.0161	2.824	0.0741
Factor-B (Fertilizer doses)	2	0.80110***	1.5146***	0.6944***	15.805**	18.4241***
A x B	10	0.09580***	2.8823***	4.4564***	205.267***	0.3728***
Error B	24	0.00012	0.0023	0.0147	1.357	0.0082
Total	53					

Conclusions and Recommendations

Sudan Grass hybrid is highly adaptable, productive and produced the maximum green fodder yield (economic) as compared to other sweet sorghum varieties. The highest fertilizer dosage of NPK @ (150:120:100 kg ha^{-1}) proved to be the best among other lower fertilizer doses because this fertilizer dose resulted the maximum green fodder yield and other yield contributing parameters. Fertilizer dose of NPK @ (150:120:100 kg ha^{-1}) also increased the Baggass % which is used in many industries for chipboard making as well as for energy production. But on the other hand fertilizer dosage of NPK @ (100:80:60 kg ha^{-1}) is feasible and have maximum results for the production of Sugar and ethanol parameters e.g. (Reducing sugar, Brix %, Pol % and Purity % of juice).It is recommended that the Sudan Grass hybrid combined with the fertilizer dose of NPK @ (150:120:100 kg $^{-1}$) performed the best results on the green fodder yield and other yield contributing parameters and recommended for general cultivation for fodder purpose. For the sugar and ethanol production there is need for further study to evaluate more varieties of Sweet Sorghum to ensure better results for sugar and ethanol production.

Novelty Statement

Sudan grass and sweet sorghum varieties are highly adaptable and productive for green fodder production. However, their utilization as sugar crops is limited. These results underscore the potential of sweet sorghum varieties as sources of sugar, ethanol, and green fodder.

Author's Contribution

Faisal Ali: Conducted the experiments.
Abdul Aziz Khakwani and Iqtidar Hussain: Supervised the experiments.
Ghazanfar Ullah and Muhammad Mamoon ur Rashid: Helped in statistical analysis.
Atiq Ahmad Ali Zai: Wrote the manuscript.
Zuhair Hasnain: Refined the manuscript.
Sara Zafar: Helped in planning of experiments.
Muhammad Naeem: Helped in writing the manuscript.

Conflict of interest
The authors have declared no conflict of interest.:

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