Nitrogen response of sweet sorghum genotypes during rainy season

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Sweet sorghum (*Sorghum bicolor* (L.) Moench) is a smart biofuel crop, which can be grown under tropical rainfed conditions without sacrificing food and fodder security. Three sweet sorghum cultivars (viz. ICSA 52 × SPV 1411, CSH 22 SS and ICSV 93046) were grown under six nitrogen levels (0, 30, 60, 90, 120, 150 kg ha^{-1}) on Vertisols during two rainy (*kharif*) seasons at ICRISAT, Patancheru, India. The results from two-year trial indicated that out of three sweet sorghum cultivars evaluated, sweet sorghum hybrid CSH 22 SS produced highest green stalk (46.90 t ha^{-1}) and ethanol yield (1940 l ha^{-1}) compared to other cultivars. The three cultivars responded well to applied N doses up to 150 kg ha^{-1}, however, application of N beyond 90 kg ha^{-1} did not result in any significant increase in grain yield and economic returns. Net economic returns of Rs 32,898 ha^{-1} (US$ 601.21 ha^{-1}) were significantly higher with 90 kg N ha^{-1} application as compared to other levels of fertilization. It is concluded that for obtaining the highest green stalk yield, ethanol yield and thereby maximum economic returns, sweet sorghum cultivar, viz. CSH 22 SS should be fertilized with 90 kg N ha^{-1}.

Keywords: Economic returns, nitrogen, potential ethanol yield, sweet sorghum.

Introduction

WITH a looming energy crisis and climate change, there is an urgent need to explore for alternative energy solutions. The rapid depletion of world fossil fuel reserves, the unprecedented rise in diesel prices, along with increased consumption and vulnerability in the supply chain presents an ideal opportunity for biodiesel/biofuels. In 2003, the Government of India (GoI) implemented a policy that implied a mandatory blending of 5–10% ethanol with petrol since October 2008 which has increased the demand for ethanol at 0.8 million tonnes year^{-1} ethanol during 2011–12 in India[1]. In the future, further increase in demand for alternate commercial raw material like sweet sorghum may be utilized as supplementary source for sugarcane industry and jaggery preparation along with grain and fodder.

Sweet sorghum may be considered as an ideally ‘smart crop’ as it produces food, feed, jaggery and sugar. This crop is similar to grain sorghum having fast growth, wider adaptability and high biomass producing ability with sugar-rich stalks, known to have good potential for ethanol production[2]. It is well adapted to sub-tropical[3] and temperate regions of the world and is highly efficient in biomass production with low water requirement[4,5] and short growing season[6]. The sugar content in the juice extracted from sweet sorghum varies from 14 to 23% brix and has a great potential for jaggery, syrup and most importantly fuel alcohol production[2].

The genotypes with the desirable yield attributes improve the green stalk yield to influence the potential ethanol yield of sweet sorghum. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and National Agricultural Research Systems (NARSs) in India are actively pursuing the improvement of sweet sorghum and promising cultivars have been released in India. The genotypes with high stalk yield, lodging resistance, high percentage of extractable juice and high brix content, coupled with resistance to diseases and drought are preferred for biofuel production[7]. Sweet sorghum varieties differ widely in their adaptation to various soil and climatic conditions[8] and potential ethanol production[9–11]. In the semi-arid region of southern India, the hybrid sweet sorghum variety, CSH 22 SS promises good yield[9,12,13].

For the high yielding varieties, nitrogen (N) is the most important plant nutrient for productivity improvement[14]. Nitrogen recommendation varies with expected yield, soil properties, cultivars and cropping sequence[12,15–19]. In general, N requirement of sweet sorghum is less than that of other alternative biofuel crops such as sugarcane[20] and maize[21]. Inappropriate application of N fertilizer is the reason for used inefficient fertilizer protocol[22] that might affect the environment[23–25]. Indeed, N appears as the most used crucial nutrient that greatly affects sorghum’s use for bio-fuel production. Very little research has been done to test how nitrogen fertilization affects the production of ethanol from sweet sorghum grown in the field.

This article summarizes the results obtained from experiments conducted during two years in the rainy (June–October) season on Vertisols at the ICRISAT farm in Patancheru, India. The major objectives of this study

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were to identify appropriate agronomic practices including N fertilizer rate and suitable genotype for enhancing productivity and resource use efficiency of sweet sorghum.

Materials and methods

Experimental site

Field experiments were conducted during rainy seasons of 2010 and 2011 under protected irrigation at the ICRISAT farm in Patancheru. Soils of the experimental sites were medium (depth) black having a depth of 150 cm, clayey in texture and alkaline in pH (7.9–8.1). The soil chemical analysis clearly showed that the soil is low in nitrogen, medium in phosphorus and high in potash (Table 1). The sites selected for the experiment were different in each season, but were located in the same block and were kept fallow during the preceding post-rainy season to reduce variation in soil fertility especially for N. The climate is semi-arid with an average annual rainfall of 898 mm, of which about 781 mm is distributed over June to October (*kharif* season) through south-west monsoon, and about 87 mm rainfall falls during November to April (post-rainy season). The chemical analysis of the soil at the experimental site showed that the soil was low in total nitrogen (N), low to moderate in available phosphorus (P) and high in available potassium (K).

Field experiment

A split–split plot design was adopted for field experiments. Three genotypes, viz. CSH 22 SS, ICSV 93046 and ICSA 52 × SPV 1411 were used as main plots and six N application rates of 0, 30, 60, 90, 120 and 150 kg ha^{-1} were treated as sub plots. Thus, there were a total of 18 combinations of treatments and each of them had 3 replications. The gross size for each plot was 9 m × 7.5 m (67.5 sq. m).

Field operations

The crop was sown on 25 June 2010 and 27 June 2011 in the rainy seasons after good monsoon rains. For maintaining optimum plant population, gap filling was done at 7–8 days after sowing (DAS), and two thinning operations were done at 15 and 25 DAS. Phosphorus (40 kg ha^{-1}), potassium (40 kg ha^{-1}) and 50% of the total N added were applied at the time of sowing. The remaining N was applied in another two splits: 25% N at vegetative growth stage (30 DAS) and remaining 25% N at boot stage (55–60 DAS). Two intercultivation operations were done at 20 and 40 DAS; and one hand weeding was carried out at 25 DAS. The harvesting of the experimental crop was performed on 13 October 2010 and 17 October 2011.

Yield parameters

Sorghum plants were harvested at physiological maturity to measure total biomass and juice yield. Immediately after harvest, canes were cleaned and crushed using three-roller mill to extract juice. Sugar content in the juice was recorded using digital hand-held refractometer (model PAL-1). Potential ethanol yield was obtained using the equation[26]

$$\text{Potential ethanol yield (kl ha}^{-1}\text{)} = \text{Juice yield (l ha}^{-1}\text{)} \times \frac{\text{Sugar content (brix \%)}}{100} \times 0.85/1.76,$$

where 0.85/1.76 is the factor coefficient used for calculating potential ethanol yield[27].

Crop samples were harvested from 36 sq. m area (6 m × 6 m) for yield estimation per hactare. First, the analysis of variance (ANOVA) for the annual data was performed in split–split plot design using GenStat software. Data were combined across the years for pooled analysis and analysed using statistical software GenStat (version 13). In pooled analysis, the data were tested for homogeneity of the error variance by using *F*-test method. Analysis of variance method (95% confidence level) was used to compare the effects of the treatments on observed parameters.

Economic analysis was carried out using the sale price finalized in the sweet sorghum bioethanol project funded by the National Agricultural Innovation Project (NAIP). The prices finalized by the committee were Indian rupees 8000 per mg for green stalk yield and 10,000 per mg for grain yield during 2010 and 2011 (US$ 1 = Rs 55).

Results and discussion

Yield attributes and yield

The results of pooled analysis of variance showed that there were significant differences as regards to different yield attributes with varied genotypes under study (Table 2). Significantly highest plant height and grain yield were recorded for genotype ICSA 52 × SPV 1411 whereas the highest values for brix, green stalk yield and juice yield were recorded for CSH 22 SS. Similar variation between genotypes for grain yield and green stalk yield was also reported by others[28].

Ethanol conversion efficiency of sweet sorghum juice is related to both juice yield and the sucrose content in the juice, which in turn is indicated by the brix reading. As regards pooled analysis of brix%, the data indicated

Table 1. Total N, available P and K in the soil at the experimental sites (2010–11)

Soil depth (cm)	Total nitrogen (kg/ha)	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
0–15	1160–1365	12.8–13.2	455–581
15–30	928–991	4.3–4.8	338–367
30–60	586–613	1.2–1.5	272–297

Table 2. Growth–yield attributes and yield of *kharif* sweet sorghum genotypes (pooled data of 2010 and 2011)

Treatment	Plant height (cm)	Brix%	Green stalk yield (t/ha)	Juice yield (t/ha)	Grain wt (q/ha)
Genotypes					
ICSA 52 × SPV 1411	297.6	15.57	41.51	20.10	13.17
CSH 22 SS	288.6	17.97	46.90	22.11	10.25
ICSV 93046	287.9	15.10	37.34	18.14	8.08
SE ±	2.9	0.44	1.64	0.48	0.99
LSD at 5%	7.5	2.20	7.04	2.08	2.15
Nitrogen level (kg/ha)					
N_1 – 0	256.0	14.15	33.91	15.74	6.60
N_2 – 30	272.9	15.28	37.52	17.28	8.21
N_3 – 60	286.5	16.21	41.36	19.34	10.13
N_4 – 90	309.2	17.28	45.46	22.22	12.33
N_5 – 120	309.7	17.37	46.28	22.76	12.87
N_6 – 150	314.0	17.39	46.97	23.02	12.85
SE ±	7.2	0.18	0.32	0.86	0.59
LSD at 5%	15.3	0.39	0.68	1.82	1.25
Interaction (G × N)					
SE ±	13.3	1.47	1.71	1.44	1.36
LSD at 5%	NS	NS	NS	NS	NS
G mean	291.4	16.28	41.92	20.12	10.50

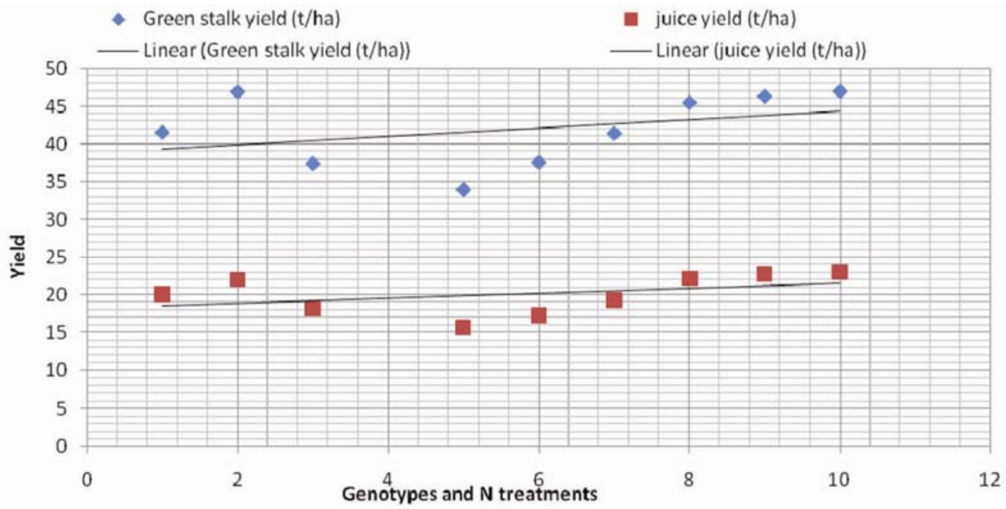

Figure 1. Linear relationships between green stalk yield and juice yield under different treatments.

that the hybrid CSH 22 SS recorded significantly highest brix% when compared with the genotypes ICSA 52 × SPV 1411 and ICSV 93046. As sweet sorghum juice is extracted from the stem, higher the green stalk yield, higher is the juice yield. Any input or management technology that helps the genotype to attain its potential green stalk yield can, therefore, help to increase the juice yield and thereby fermentable sugar yield and ethanol yield in

Table 3. Fermentable sugar yield, ethanol yield and economics of *kharif* sweet sorghum genotypes (pooled data of 2010 and 2011)

Treatment	Yield for fermentable sugar (l/ha)	Ethanol yield (l/ha)	Total gross income (Rs/ha)	Net economic returns (Rs/ha)	B : C ratio
Genotypes					
ICSA 52 × SPV 1411	2718	1544	50530	30335	2.51
CSH 22 SS	3414	1940	52452	32256	2.60
ICSV 93046	2344	1332	41692	21496	2.06
SE ±	303.8	72.6	2393	2039	0.02
LSD at 5%	697	142.7	8296	5296	0.05
Nitrogen level (kg/ha)					
N_1 – 0	1907	1084	37123	17673	1.91
N_2 – 30	2303	1308	41974	22249	2.13
N_3 – 60	2683	1525	47358	27308	2.37
N_4 – 90	3275	1861	53248	32898	2.62
N_5 – 120	3370	1915	54522	33872	2.65
N_6 – 150	3414	1940	55125	34175	2.65
SE ±	113.4	64.5	611.5	612.4	0.03
LSD at 5%	241.6	137.4	1303.5	1305.2	0.07
Interaction (G × N)					
SE ±	352.7	200.5	8762	2581	0.13
LSD at 5%	NS	NS	NS	NS	NS
G mean	2825	1605	48225	28029	2.39

sweet sorghum. A significant influence on juice yield, fermentable sugar yield and ethanol yield was recorded with various levels of nitrogen.

Increasing applied nitrogen recorded profound significant effect on the yield-attributes and yield up to 150 kg N ha^{-1}; however, the response was linear on yield-attributing characters and yields up to 90 kg N ha^{-1} but, further increase in N level did not improve grain yield significantly. The results are in agreement with those of earlier researchers[26,29,30]. Similarly, a linear significant increase in juice yield and potential ethanol yield was recorded up to 90 kg N ha^{-1} during all the seasons of experimentation and in pooled analysis, wherein the increase in juice yield of sweet sorghum over lower levels of nitrogen ranged from 32% to 60% (refs 30–32).

Increase in potential ethanol yield relative to N fertilizer was primarily due to increase in fresh stalk yield, juice yield and sugar content. Similar results were also reported elswhere[10,17,32–35]. A strong correlation between green stalk and juice yield (Figure 1) is clearly envisaged by a linear relationship between green stalk and juice yield. This is in conformity to the findings of earlier researchers[32,36].

Economics

Table 3 indicates that the hybrid CSH 22 SS recorded significantly the highest gross and net economic returns and B : C ratio compared to other genotypes. However, it was found at par with ICSA 52 × SPV 1411 for B : C ratio. There was a linear significant effect with different nitrogen levels up to 90 kg N ha^{-1} whereas further increase in N level did not produce any significant increase in economic returns. The results are in conformity to those of earlier researchers[2,30]. Significantly, the highest B : C ratio was recorded with genotype CSH 22 SS and with regard to nitrogen levels, application of 90 kg N ha^{-1} recorded significantly the highest B : C ratio.

Conclusions

Out of three sweet sorghum varieties (CSH 22 SS, ICSV 93046 and ICSA 52 × SPV 1411) evaluated, the plant growth and yield parameters of hybrid CSH 22 SS were significantly superior to others. The CSH 22 SS showed higher green stalk and grain yield over ICSV 93046 and ICSA 52 × SPV 1411, whereas positive crop yield response to increasing N application was observed for all the three varieties. Increased N levels also increased the yield only up to 90 kg N ha^{-1}. Economic analysis also suggested greater net returns from CSH 22 SS at 90 kg N ha^{-1}. On the basis of the results on economics and estimated nitrogen use efficiency, we conclude that the hybrid CSH 22 SS with N fertilizer at 90 kg ha^{-1} performs better than other varieties.

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ACKNOWLEDGEMENTS. We thank Drs Ashok Kumar, Ravinder Reddy and P. Srinivas Rao, Sorghum Breeding, ICRISAT for their help and providing the seeds of different cultivars for sweet sorghum trials. We also thank financial support by the NAIP–ICAR for conducting the research as a part of NAIP–ICAR–Sweet sorghum bioethanol project.

doi: 10.18520/cs/v110/i9/1699-1703