



Evaluation of sweet sorghum (*Sorghum bicolor*) genotypes for biomass, sugar and ethanol production under different levels of nitrogen

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ABSTRACT

Sweet sorghum [*Sorghum bicolor* (L.) Moench] stalks contain high fermentable sugar and thus have potential to produce bio-ethanol along with grains and crushed dry matter. Its cultivars differ in production potential, adaptation, duration and response to nitrogen level under different agro-climatic conditions. A field experiment was conducted at New Delhi, during *khariif* season of 2009 and 2010 to evaluate three sweet sorghum genotypes (varieties: RSSV 9, SSV 84, and hybrid: CSH 22 SS) under four nitrogen levels (0, 50, 100 and 150 kg N/ha for growth, biomass, fermentable sugar and potential ethanol yield. In the first year, except green biomass, juice yield, fermentable sugar yield and expected ethanol yield recorded significant increase up to 100 kg N/ha, while green biomass yield responded up to 150 kg N/ha. In the second year, all yield parameters except brix (%) showed marked improvement up to 150 kg N/ha. Expected ethanol yield recorded 83.4% and 77.7% increase due to application of 150 kg N/ha over control in 2009 and 2010 respectively. Among the genotypes, hybrid CSH 22 SS showed its significant superiority in the above mentioned yield parameters over varieties, except brix (%), which was the highest in RSSV 9. Hybrid CSH 22 SS recorded 112% and 34% increase in ethanol yield over SSV 84 and RSSV 9, respectively. Interaction effect of nitrogen × genotypes for all above characters, except brix (%) was significant. Hybrid CSH 22 SS responded significantly up to 150 kg N/ha, while in case of varieties response to N application was significant only up to 100 kg N/ha. Net return with 150 kg N/ha fertilizer application recorded 116.9 and 116.3% increase over control in 2009 and 2010 respectively. On an average hybrid CSH 22 SS produced net returns of ₹ 41 540 which was 135 and 41% higher than SSV 84 and RSSV 9 respectively.

Key words: Biomass yield, Ethanol yield and sweet sorghum, Genotypes, Nitrogen

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is similar to grain sorghum with exception of a sugar-rich stalk. In the ever growing scenario of food and energy crisis, sweet sorghum is going to play an important role in providing biofuel that could be blended with petrol. Sweet sorghum is being cultivated for ethanol production in different countries to meet the increasing demand of energy. The juice from fresh green millable cane is used for syrup and alcohol production. The ethanol production process is more eco-friendly than ethanol produced from that of sugarcane and its molasses. Because ethanol burning quality is superior and emits less sulphur than from sugarcane and has high octane rating (Reddy, 2006). Sweet sorghum grains, stem and trash can be used for food, feed, sugar, alcohol, syrup, fodder, fuel, bedding, roofing, fencing and paper making. In India, sweet sorghum has been used for nearly 150 years to produce concentrated syrup with a distinctive flavour (Lakkana *et al.* 2009). During shortage of sugarcane molasses in some years, there is an opportunity for sweet sorghum to provide

alternative raw material in the ethanol industry.

Sweet sorghum varieties differ greatly in their qualities and in their adaptation to various soil and climatic conditions (Lakkana *et al.* 2009). The varieties with a 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 (Morris 2006). So, cultivar choice strategy is important to attain higher stalk and juice yield in sweet sorghum.

Nitrogen is the most important plant nutrients required for crop production and is required in large quantities (Balasubramanian *et al.*, 2010). Although N plays a very important role for good growth and development of sorghum, over-fertilization is often harmful as it results in lower yield and quality (Parikshya Lama Tamang 2010). Nitrogen recommendations will vary with expected yield, soil texture, cultivars and cropping sequence (Amal 2007). Keeping these issues in view, the present study was conducted to determine suitable genotype and nitrogen level for higher productivity and economic returns from sweet sorghum cultivation in the north-western plains of India.

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MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) season of 2009 and 2010 at the research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi. The aim of the study was to understand the interactive effect of nitrogen levels and genotypes on growth, sugar and bio-ethanol yield of sweet sorghum. The experiment was conducted using a split-plot design with three replications. Four levels of nitrogen (0, 50, 100 and 150 kg N/ha) were assigned to the main plots and three sweet sorghum genotypes to the sub plots. Of the sweet sorghum genotypes tested, two varieties (RSSV 9 and SSV 84) were developed by MPKV Rahuri, and one hybrid (CSH 22 SS), was developed by the Directorate of Sorghum Research, Hyderabad. The soil of experimental site was sandy loam in texture with pH of 7.82 and 178, 13.6, 218 kg/ha available of NPK and 0.36% organic carbon. As per N treatment, $\frac{1}{2}$ of the N, the full recommended dose of phosphorus (60 kg P_2O_5 /ha) in the form of single super phosphate and recommended dose of potassium (50 kg K_2O /ha) as muriate of potash were applied as basal application. The remaining $\frac{1}{2}$ of the N was applied at 45th days after sowing. Crop was sown on 9 July and 30 June in 2009 and 2010 respectively at 60 cm row-to-row spacing. At appropriate emergence stage, plant-to-plant spacing of 20 cm was maintained after thinning excess plant. Atrazine was sprayed as pre-emergence for the control of weeds. Beside, atrazine spray, two hand weedings were done at 20 and 40 days after sowing for effective weed control. Thiodan was

sprayed twice to protect crop from stem borer. The total rainfall during crop growth season was 521 mm in 2009–10 and 784 mm in 2010–11. Crop received five irrigations (22 August, 22 September and 1, 12, 26 October) during 2009 and three irrigations (10, 27 August and 10 October) during 2010. Growth attributes, viz plant height, leaf area index (LAI) and total dry matter yield of the crop were recorded at 30, 60, 90, 120 days after sowing (DAS) and physiological maturity stage. At each sampling stage, five plants from the sample rows of each plot were harvested close to the ground. Total leaf area was measured using a standard LI-COR leaf area meter (Model LI-3100). For obtaining of total green biomass yield, juice yield, yield of fermentable sugar and bio-ethanol yield from stalks, sweet sorghum plants were harvested at physiological maturity stage. Immediately after harvest, canes from each net plot were cleaned and crushed using three-roller squeezer to extract juice. Brix percentage in juice was recorded using digital hand refractometer model HI 96801. Yield of fermentable sugars and potential alcohol yield per hectare were obtained using following formula (Spencer and Meade 1963):

Yield of fermentable sugars (t/ha) = Juice yield (t/ha) × Brix percentage × 0.85

Potential ethanol yield (l/ha) = Juice yield (t/ha) × Brix percentage 0.85/1.76

For calculating economic of sweet sorghum from ethanol production, government of India ethanol sale price of 27/litre and ethanol processing cost of 13.25/litre were used (Amit

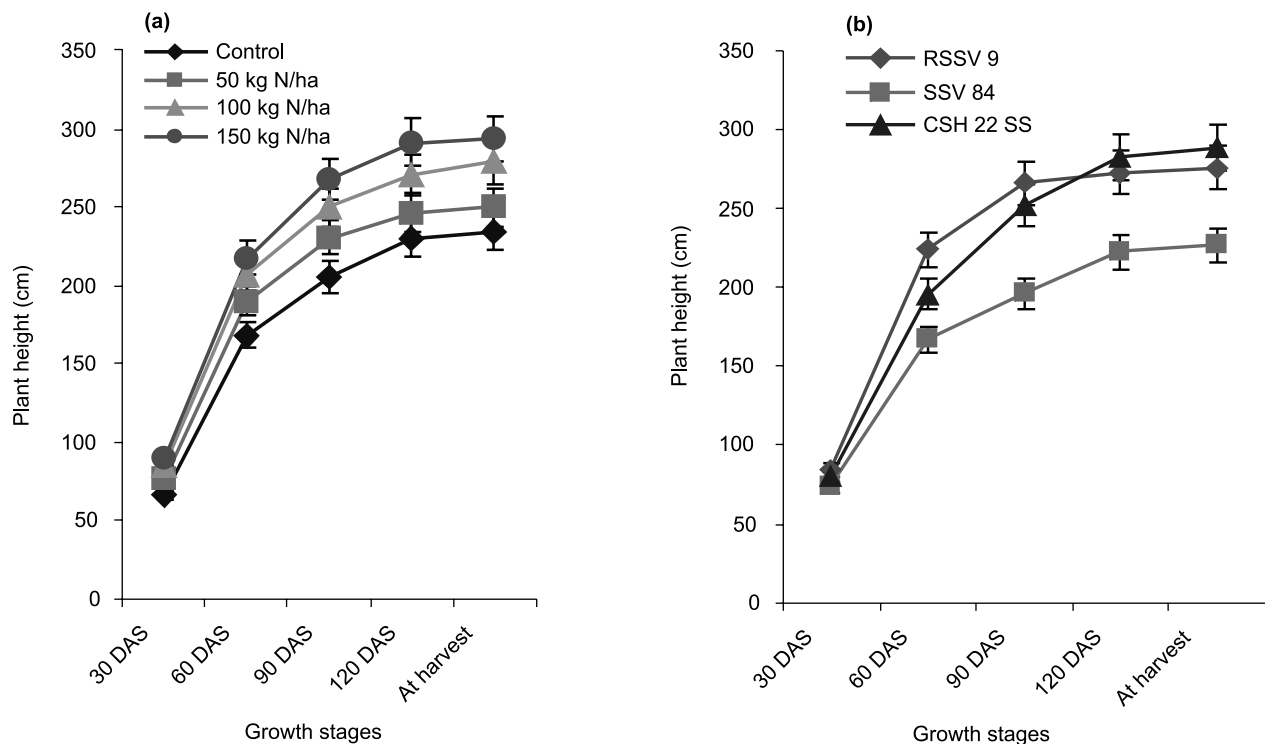


Fig 1 Plant height of sweet sorghum as affected by nitrogen levels (a) and genotypes (b) at different growth stages

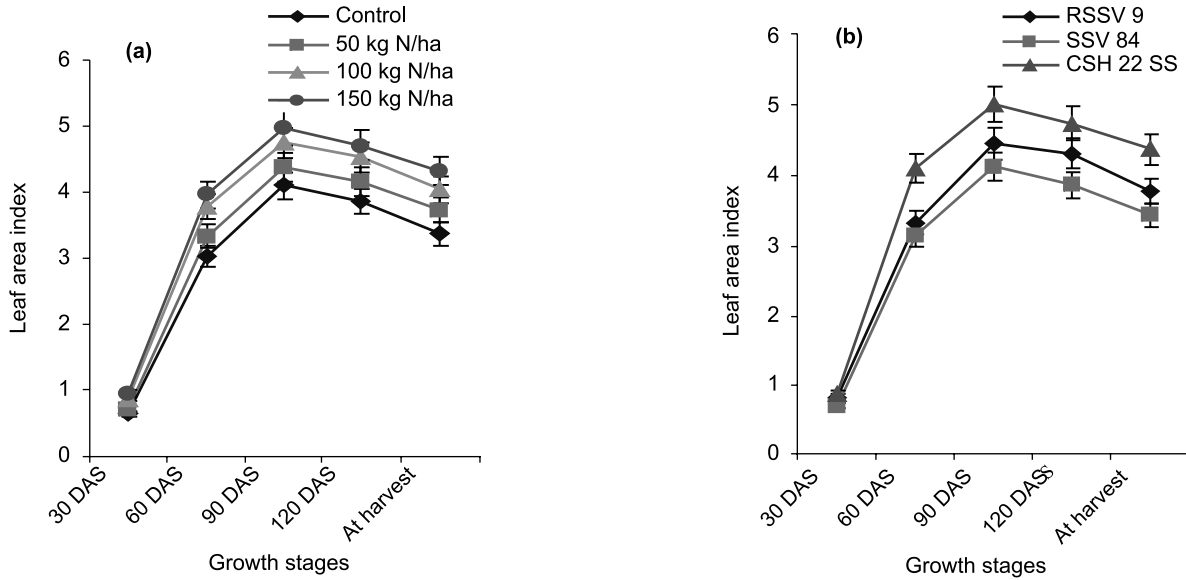


Fig 2 LAI of sweet sorghum as affected by nitrogen levels (a) and genotypes (b) at different growth stages

and Thom 2010). The data recorded were tabulated and analyzed statistically using Statistical Package for the Social Sciences (SPSS) version 18 software and LSD test at 5% probability level was applied to compare the differences among the treatments, means.

RESULTS AND DISCUSSION

Growth attributes

The data on plant height, leaf area index (LAI) and total dry matter (TDM) at different growth stages of crop under different treatments have been presented in Figs 1, 2 and 3. LAI recorded increase up to 90 DAS and thereafter it declined, whereas plant height and TDM increased at increasing rate

up to 90 DAS and thereafter both the attributes increased at decreasing rate. Application of nitrogen (N) increased the plant height, LAI and TDM significantly at all stages of samplings compared to control. N application caused marked increase in plant height up to 150 kg N/ha, while LAI and TDM responded only up to 100 kg N/ha. Effects of N levels on plant height, LAI and TDM were not marked at 30 DAS. With the advancement in the growth of plant, effects of N levels become more conspicuous and maximum variances were observed at 120 DAS and at harvest. Increase in plant height and LAI is due to the increase in the number of nodes and internodes, increase in the internodes length and increase in number of leaves and their length and width. These

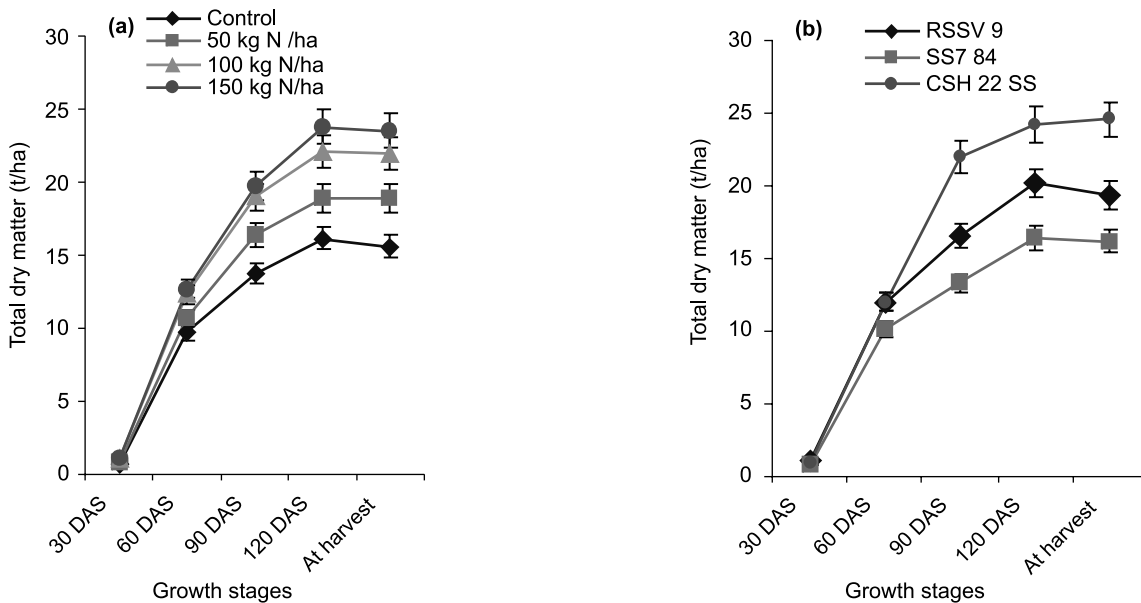


Fig 3 Total dry matter of sweet sorghum as affected by nitrogen levels (a) and genotypes (b) at different growth stages

variations in growth attributes may be ascribed to the structural and functional role of nitrogen in plant system (Sylvester *et al.* 2010). The reduction in leaf area at maturity was due to decrease in leaf number (leaf fall) and also due to translocation of metabolites for growth and formation of reproductive parts.

There was significant difference in plant height, LAI and TDM among sweet sorghum genotypes (Figs 1, 2, 3). In the genotypes, variation in LAI, plant height and TDM were not marked at 30 DAS, which become significant with the advancement of growth stages. Maximum variations in plant height and TDM among the genotypes were observed at harvest, while in case of LAI, maximum variations were found at 90 DAS. CSH 22 SS produced the maximum LAI and TDM compared to other genotypes at all growth stages except 30 and 60 DAS where it was only superior to SSV 84 during both years. RSSV 9 recorded maximum plant height up to 90 DAS, thereafter hybrid CSH 22 SS recorded significantly more plant height than varieties. SSV 84 produced the lowest plant height at all growth stages. These variations among the genotypes may be attributed for their genetic make up. Similar variations in LAI, plant height and TDM among the sweet sorghum genotypes and due to nitrogen were reported by Amal *et al.* (2007), Kumar *et al.* (2008) and Sylvester *et al.* (2010).

Yield and yield attributes

The data pertaining on total green biomass yield, juice yield, brix (%), fermentable sugar yield and ethanol yield has been presented in Tables 1, 2. Nitrogen fertilization up to 150 kg N/ha markedly increased the total green biomass yield, juice yield, fermentable sugar yield and ethanol yield compared to other levels in both the years. An increase to the tune of 42%, 76.7%, 80.2% and 80.5% in total green biomass yield, juice yield, fermentable sugar yield and ethanol yield, respectively was recorded due to application of 150 kg N/ha over control. Increase in brix (%) with application of nitrogen was significant only up to 100 kg N ha⁻¹ in both the seasons. Per cent increase in brix (%) due to application of 100 kg/N ha was 4.3 and 3.4% over control during 2009 and 2010 respectively. Pholsen and Sornsungnoen (2004) reported that application of nitrogen fertilizer in most cases increased brix value. These variations in yield and yield attributes due to N application may be traced to the variation in growth attributes. Increase in ethanol yield due to nitrogen in sweet sorghum genotypes was primarily due to increase in fresh stalk yield, juice yield and sugar concentration. The results were in agreement with those obtained by Kumar *et al.* (2008), Poornima *et al.* (2008) and Ratnavathi *et al.* (2010).

The differences in total green biomass yield, juice yield, brix (%), fermentable sugar yield and ethanol yield were significant among the three genotypes under investigation. Hybrid CSH 22 SS was superior to varieties, except brix (%), which was the highest in RSSV 9. In the varieties,

Table 1 Effect of nitrogen levels and genotypes on GBY, JY, JP, Brix (%), FSY and EY and economics of sweet sorghum at physiological maturity

Treatments	2009							2010								
	GBY	JY	Brix (%)	FSY	EY	GR	NR	Net B:C	GBY	JY	Brix (%)	FSY	EY	GR	NR	Net B:C
<i>Nitrogen levels (kg/ha)</i>																
Control	71.44	15.33	17.90	2.35	1.33	46.02	17.86	0.60	74.64	16.30	17.74	2.46	1.40	47.79	18.58	0.61
50	85.24	18.29	18.39	2.88	1.63	56.68	24.32	0.72	87.65	19.18	17.89	2.91	1.65	57.69	24.85	0.73
100	98.39	24.57	18.67	3.93	2.24	75.59	35.04	0.82	102.54	25.64	18.35	3.98	2.26	77.81	36.72	0.85
150	102.32	27.12	18.46	4.29	2.44	82.20	38.74	0.86	105.50	28.77	17.96	4.38	2.49	84.55	40.19	0.88
SEm±	1.06	1.20	0.04	0.19	0.11	4.54	2.54	0.02	2.44	0.71	0.13	0.12	0.07	2.68	1.59	0.03
CD (P=0.05)	3.65	3.56	0.14	0.65	0.37	11.10	6.22	0.04	8.38	2.46	Ns	0.37	0.21	6.55	3.89	0.07
<i>Genotypes</i>																
RSSV 9	86.27	20.68	18.73	3.32	1.89	64.12	28.43	0.77	89.70	22.16	18.82	3.54	2.01	67.87	30.32	0.79
SSV 84	72.53	13.90	18.12	2.16	1.22	44.47	17.54	0.63	74.40	14.66	17.57	2.19	1.24	45.23	17.85	0.63
CSH 22SS	109.25	29.40	18.23	4.61	2.62	86.78	41.00	0.85	113.66	30.59	17.56	4.57	2.60	87.78	42.08	0.88
SEm±	1.72	0.89	0.06	0.16	0.08	2.81	1.66	0.01	1.66	0.84	0.11	0.12	0.06	2.37	1.45	0.01
CD (P=0.05)	5.11	2.63	0.20	0.47	0.26	8.34	4.91	0.03	4.94	2.51	0.33	0.37	0.22	7.05	4.31	0.03

Table 2 Interaction effect of nitrogen levels × genotypes on ethanol yield, yield attributes and economics of sweet sorghum at physiological maturity stage

Treatment	2009							2010						
	GBY	JY	FSY	EY	GR	NR	Net B:C	GBY	JY	FSY	EY	GR	NR	Net B:C
N0 × G1	70.4	16.8	2.6	1.5	50.14	20.00	0.64	75.8	17.5	2.7	1.6	52.05	20.88	0.66
N0 × G2	59.3	10.2	1.6	0.9	32.56	10.50	0.47	61.9	11.0	1.6	0.9	33.77	10.97	0.47
N0 × G3	84.6	19.0	2.9	1.6	55.36	23.08	0.69	86.2	20.4	3.0	1.7	57.55	23.89	0.70
N1 × G1	84.5	18.0	2.9	1.6	57.12	24.79	0.76	85.8	19.1	3.0	1.7	59.21	25.75	0.76
N1 × G2	72.0	12.9	2.0	1.1	41.23	15.54	0.59	73.8	13.3	2.0	1.1	41.10	15.38	0.59
N1 × G3	99.2	24.0	3.7	2.1	71.69	32.63	0.82	103.3	25.1	3.7	2.1	72.76	33.41	0.83
N2 × G1	93.3	22.8	3.7	2.1	71.90	32.97	0.82	97.0	24.6	4.0	2.3	77.44	35.96	0.85
N2 × G2	76.3	15.3	2.4	1.4	49.32	20.42	0.69	77.7	15.8	2.4	1.4	49.41	20.44	0.70
N2 × G3	125.6	35.6	5.7	3.2	105.55	51.75	0.95	132.9	36.5	5.5	3.1	106.59	53.75	1.00
N3 × G1	96.9	25.1	4.0	2.3	77.33	35.96	0.86	100.1	27.4	4.4	2.5	82.80	38.67	0.87
N3 × G2	82.4	17.2	2.7	1.5	54.76	23.70	0.76	84.1	18.5	2.8	1.6	56.63	24.61	0.76
N3 × G3	127.6	39.1	6.2	3.5	114.51	56.57	0.95	132.2	40.4	6.0	3.4	114.23	57.29	1.00
SEm ±	3.4	1.6	0.3	0.1	4.55	2.68	0.02	3.36	1.4	0.2	0.1	3.78	2.35	0.03
CD (P=0.05)	10.2	5.3	0.9	0.5	16.68	9.82	N S	9.9	5.0	0.7	0.4	14.02	8.63	N S

GBY, Green biomass yield (t/ha); JY, juice yield (kl/ha); FSY, fermentable sugar yield (t/ha); EY, ethanol yield (kl/ha); GR, gross returns ($\times 10^3$ ₹/ha); NR, net returns ($\times 10^3$ ₹/ha) and B:C, benefit : cost ratio; N₀, control, N₁, N₂ and N₃ are 50, 100 and 150 kg N/ha; G₁, RSSV 9; G₂, SSV 84 and G₃, CSH 22 SS sweet sorghum genotypes

RSSV 9 was significantly superior to SSV 84. Based on two years average, CSH 22 SS recorded 47.9%, 110.5%, 111% and 112.2% increase in total green biomass yield, juice yield, fermentable sugar yield and ethanol yield respectively compared to SSV 84. Increase in brix (%) of RSSV 9 over SSV 84 was 5.3%. Variations in the growth parameters among the genotypes account for variation in green biomass yield and juice yield. This in turn helped in absorption of large amount of solar radiation and thus production of large quantities of photosynthates, which were eventually accumulated in stalks. Plants of hybrid CSH 22 SS produced greater expected ethanol yield, which was the natural corollary of juice yield. Similar findings were expressed by Propheter *et al.* (2010) and Wortmann *et al.* (2010).

Interaction effect of nitrogen × genotypes on total green biomass yield, juice yield, fermentable sugar yield and ethanol yield was significant (Table 2). Hybrid CSH 22 SS responded significantly up to 150 kg N/ha, while in case of varieties response to N application was significant only up to 100 kg N/ha. This variation between N levels and genotypes is attributed to variation in genetic potential of genotypes. The results are in agreement with that of Reddy (2006), who found that hybrids respond to higher levels of nitrogen, (more than 100 kg N/ha) compared to traditional varieties.

Economics

Economic of ethanol production from sweet sorghum was significantly influenced by various nitrogen levels as well as genotypes (Tables 1, 2). The highest net returns and B:C ratio was observed in plots treated with 150 kg N/ha followed by 100 kg N/ha. Application of 150 kg N/ha recorded

116.9% and 116.3% increase in net return compared to control in 2009 and 2010 respectively. Among genotypes CSH 22 SS produced the maximum net return and B:C ratio. Net return obtained due to CSH 22 SS compared to RSSV 9 showed 44% and 39% increase in 2009 and 2010, respectively. The lowest net returns and B:C ratio was recorded in SSV 84. Interaction effects of nitrogen × genotypes on net returns in both seasons and on B: C ratio in 2009 was significant. Net returns and B: C ratio of CSH 22 SS recorded more increase at high levels of nitrogen compared to varieties (Table 2). These results are in conformity with earlier observations (Reddy *et al.* 2006).

Correlation studies

The correlation coefficient studies on two years pooled data between ethanol yield and juice quality parameters and

Table 3 Correlation between ethanol yield with growth, juice quality and yield components of sweet sorghum

Parameter	Correlation coefficient		
	2009	2010	Pooled
Height (cm)	0.905**	0.892**	0.878**
LAI	0.878**	0.934**	0.874**
TDM (tonnes/ha)	0.933**	0.961**	0.950**
GBY (tonnes/ha)	0.965**	0.922**	0.780**
Juice yield (kl/ha)	0.917**	0.996**	0.995**
Brix	0.728**	0.079	0.346**

** Significant at 1% TDM, Total dry matter production; LAI, leaf area index; GBY, green biomass yield

yield components at physiological maturity stage revealed that ethanol yield had positive and significant correlation with plant height ($r = 0.950$), LAI ($r = 0.874$), total dry matter ($r = 0.878$), green biomass yield ($r = 0.778$), juice yield ($r = 0.995$) and brix ($r = 0.346$) (Table 3). Similar results were reported by Reddy (2006), who observed positive and significant correlation between ethanol yield with brix (0.436), juice yield ($r = 0.648$) and green biomass yield ($r = 0.686$).

Based on this study, it is concluded that sweet sorghum hybrid CSH 22 SS is more productive and profitable than varieties RSSV 9 and SSV 84. It requires N application of 150 kg/ha for higher productivity and profitability.

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