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Nitrogen response and water use efficiency of sweet sorghum cultivars

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ABSTRACT

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is a biofuel crop, which can be grown under tropical rainfed conditions without sacrificing food and fodder security. Three sweet sorghum cultivars (CSH 22 SS, NTJ 2 and ICSV 93046) with two row spacings (60 and 45 cm) and six nitrogen levels (0, 30, 60, 90, 120, and 150 kg ha^{-1}) were grown on Vertisols during three post rainy (November to April) seasons at the ICRISAT center farm in Patancheru, India. The results showed that the row spacings (60 or 45 cm) had no influence on performance of the cultivars. Sweet sorghum hybrid CSH 22 SS produced the highest green stalk yield (45.4 Mg ha^{-1}) and grain yield (2.33 Mg ha^{-1}) compared to NTJ 2 (32.66 Mg ha^{-1} and 1.70 Mg ha^{-1}) and ICSV 93046 (38.44 Mg ha^{-1} and 2.03 Mg ha^{-1}). Net economic return from CSH 22 SS (US$ 681 ha^{-1}) was also significantly higher than that from NTJ 2 (US$ 415 ha^{-1}) and ICSV 93046 (US$ 539 ha^{-1}). All cultivars responded to applied N up to 150 kg ha^{-1}; however beyond 90 kg ha^{-1} N rate, the increase in yield was insignificant. Estimated N use efficiency (NUE) values indicated that 90 kg N ha^{-1} was an optimum N level for sweet sorghum crop. Simulated soil water balance components revealed that reduction in total transpiration due to water stress was 20 to 45% compared to the no-stress. In case of water use efficiency, CSH 22 SS showed the highest economic returns per unit volume of water input. Based on these results, it is concluded that sweet sorghum hybrid CSH 22 SS at 90 kg N ha^{-1} is the best remunerative combination for maximizing yield, economic returns and resource use efficiency.

1. Introduction

Energy security and reducing greenhouse gas (GHG) emissions are important priorities for the global community; and sustainable green bioenergy crops provide a potential solution to future energy demand. It is projected that the renewable energy sources (RES) may meet about 80% of the global energy supply by 2050 (IPCC, 2011). However, expansion of energy crops would eventually compete with food crops for land, water and nutrient resources, which may translate into increase in prices and shortage of food supply (Tenenbaum, 2008). Therefore, a balance between bioenergy and food security needs to be achieved by adopting the energy crops that complement food crops.

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is one such energy crop, which has lower water requirement, is drought and salinity tolerant (Vasilakoglou et al., 2011), has a short growing period, and is well suited to semi-arid region (Reddy and Sanjana Reddy, 2003). Sweet sorghum can transform the available water more efficiently into dry matter than most of the other C4 crops (Dercas and Liakatas, 2007); and the crop is able to utilize water from as deep as 270 cm soil depth (Geng et al., 1989). Sweet sorghum juice contains about 16–18% fermentable sugar, which can be directly fermented into ethanol by yeast with efficiency up to 93% (Christakopoulos et al., 1993; Wu et al., 2010). Ethanol produced from sweet sorghum has superior burning quality, with high octane rating and less sulphur emission (Ture et al., 1997). Significant research has been carried out during the past two decades on sweet sorghum for ethanol production (Linton et al., 2011; Massoud and Abd El-Razek, 2011) to improve crop yield and resources utilization efficiency (Zegada-Lizarazu and Monti, 2012). Sweet sorghum provides an option as a potential cash crop that can be cultivated under moderate inputs.

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 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). Sweet

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sorghum varieties differ widely in their adaptation to various soil and climatic conditions (Lakkana et al., 2009) and potential ethanol production (Chavan et al., 2009; Ratnavathi et al., 2010; Davila-Gomez et al., 2011). In the semi-arid region of southern India, the hybrid sweet sorghum variety (CSH 22 SS) seems promising with good yield (Miri and Rana, 2012; Chavan et al., 2009; Reddy et al., 2005).

For the high yielding varieties, nitrogen (N) is the most important plant nutrient for productivity improvement (Balasubramanian et al., 2010). Nitrogen recommendations vary with expected yield, soil properties, cultivars and cropping sequence (Wiedenfeld, 1984; Turgut et al., 2005; Almodares et al., 2007, 2009; Wortmann et al., 2010; Miri and Rana, 2012). In general, N requirement of sweet sorghum is less than that of other alternative biofuel crops such as sugarcane (Almodares and Hadi, 2009) and maize (Anderson et al., 1995). Inappropriate application of N fertilizer is not only inefficient (Parikshya Lama Tamang, 2010), it may also affect the environment (Jalali, 2005; Derby et al., 2009; Yang and Liu, 2010).

Crop productivity is related to plant population per unit area; however, still the impact of wide or narrow spacing on the performance of sweet sorghum crop is not clear. Recently, Wortmann et al. (2010) reported that plant population might not have any significant effect on productivity of sweet sorghum crop. However, for obtaining target productivity, Godsey et al. (2012) suggested to maintain optimum plant population of 100,000–150,000 ha^{-1}.

This paper summarizes the results obtained from experiments conducted during three years in the post-rainy (November–March) season on Vertisols at the ICRISAT farm in Patancheru, India. The major objective of this study was to identify appropriate agronomic practices including N fertilizer rate, suitable genotype and row spacing for enhancing productivity and resource use efficiency of sweet sorghum.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted during post rainy seasons of 2008, 2009 and 2010 under irrigated condition at the ICRISAT farm in Patancheru, India (17.5° N 78.5° E and altitude 545 m). Soils of experimental sites were medium black having a depth of 150 cm, clayey in texture and alkaline in pH (8.0–8.1). The sites selected for the experiment were different every season, but were located in same block and were kept fallow during preceding 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 (Table 1) revealed that the soil was low in total nitrogen (N) and low to moderate in available phosphorus (P) and high in available potassium (K).

2.2. Field experiments

A split–split plot design was adopted for field experiments. Two configurations of row to row spacing of 45 or 60 cm and plant to plant spacing of 15 cm were used as main plots to ensure plant population of 1.48×10^5 and 1.11×10^5 plants ha^{-1}, respectively. Six N application rates of 0, 30, 60, 90, 120 and 150 kg ha^{-1} were treated as sub plots. Three sweet sorghum genotypes: CSH 22 SS, ICSV 93046 and NTJ 2 were considered as sub-sub plots. Thus, there were total 36 combinations of treatments and each of them had three replications. The gross size for each plot was 9 m × 7.5 m (67.5 m^2).

2.3. Field operations

The crops were sown on 19 December in 2008, 12 December in 2009 and 26 November in 2010 post rainy seasons with pre-sowing irrigation. 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 done at 25 DAS. The crop received five irrigations during 2008–09 (7 January, 29 January, 20 February, 11 March and 2 April 2009), six during 2009–10 (9 January, 3 February, 17 February, 8 March, 18 March and 1 April 2010) and six during 2010–11 (23 December 2010; 8 January, 19 January, 5 February, 21 February, 11 March 2011). Irrigation depth for each event was 60 mm. Crop was harvested on 5 April 2009; 20 April 2010 and 6 April 2011 for the three seasons.

2.4. Field scale water balance components

A simple water balance model was used to assess the water balance components. The field water balance equation may be written by invoking the conservation of mass within a volume element:

$$\theta_t = \theta_{t-1} + R_t + I_t - E_t - T_t - DP_t - O_t \tag{1}$$

where θ is the available water [L], t is the time in days [T], R is the rainfall per unit area [L], I is the depth of irrigation [L], DP is the deep percolation losses [L], O is the runoff losses [L], E is the evaporation [L], and T is the transpiration [L].

The weather data were collected from the weather station at the ICRISAT center. Values of evaporation and transpiration were computed using FAO-56 dual coefficient method (Allen et al., 1998). This method describes the estimation of crop coefficient K_c with respect to wetting pattern of the soil by splitting K_c into two separate coefficients: the basal crop coefficient (K_{cb}) for crop transpiration and coefficient for soil evaporation (K_e).

$$ET_c = (K_{cb} + K_e)ET_0 \tag{2}$$

Basal crop coefficient (K_{cb}) is the ratio of the crop evapotranspiration and reference evapotranspiration (ET_0) when the transpiration is very close to total ET_c and evaporation is near to zero. In case of irrigated sorghum crop, as per the general guidelines, the values for K_{cb} during initial, mid-season and at end of season are 0.15, 1.10, and 0.64 (Allen et al., 1998). The evaporation component in ET_c is estimated by following three stage method described by Allen et al. (2005). Basal crop coefficient gives potential transpiration (Tp) when the water available for plant uptake is not limited. Transpiration (Tact) with water stress condition can be estimated with respect to soil moisture depletion in root zone depth (Allen et al., 2005).

Runoff was estimated using SCS curve number method (SCS, 1972). A one-dimensional tipping bucket type model was employed to simulate water movement through the soil profile. It was assumed that soil profile is divided vertically into thin layers. Once the moisture content in top layer reaches to field capacity limit, surplus water moves to the next layer downward. The upward movement of water is not considered in this model.

2.5. 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

Table 1
Total N, and available P and K in soil at the experimental site (2008–2010).

Soil depth (cm)	Total nitrogen (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
0–15	1390–1407	13.1–13.4	463–471
15–30	1018–1021	4.4–4.8	318–325
30–60	626–633	1.2–1.5	252–258

extract juice. Sugar content in the juice was recorded using digital hand-held refractometer (model PAL-1). Potential ethanol yield was obtained using the following equation (Spencer and Meade, 1963):

$$\text{Potential ethanol yield (kl ha}^{-1}) = \text{Juice yield (l ha}^{-1}) \times \frac{\text{Sugar content (brix\%)}}{100} \times \left(\frac{0.85}{1.76}\right) \quad (3)$$

where, 0.85/1.76 is the factor coefficient used for calculating potential ethanol yield (Spencer and Meade, 1963).

Crop samples were harvested from 36 m^2 area (6 m × 6 m) for ha^{-1} yield estimation. First, the analysis of variance (ANOVA) for the individual year data was done in split–split plot design using GenStat software. Data were combined across the years for pooled analysis and analyzed 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.

Agronomic nitrogen use efficiency (NUE) was estimated by formula:

$$\text{NUE} = \frac{Y_N - Y_0}{N} \quad (4)$$

where NUE is the agronomic nitrogen use efficiency (US\$ kg^{-1}), Y_N is the economic value of yield (US\$ ha^{-1}) in treatment receiving N dose of N kg ha^{-1}, and Y_0 is the economic value of yield in controlled treatment (no fertilizer). The water use efficiency values were estimated with respect to total water input and transpiration by dividing total economic value of crop produced (grain + stalk, in US$) by estimated total water use (rainfall + irrigation + initial available soil moisture, in mm) and transpiration during the growth period (mm), respectively. Economic analysis was carried out using the sale price finalized in the sweet sorghum bioethanol project funded by National Agricultural Innovation Project-Indian Council of Agricultural Research. The prices finalized by the committee were Indian Rupees 7000, 7000 and 8000 per Mg for green stalk yield and Indian Rupees 8000, 9000 and 10,000 per Mg for grain yield during 2008, 2009, and 2010, respectively (US$ 1 = Indian Rupee 55)

3. Results and discussion

3.1. Vegetative and yield attributes

Row spacings did not affect plant height and number of leaves per plant (Table 2), but significant differences were observed for N level and genotype. A linear increase in these growth attributes with increase in N level was observed up to 90 kg ha^{-1}. Further increase in N levels beyond 90 kg ha^{-1} had no significant effect. Among the genotypes, CSH 22 SS was the tallest and NTJ 2 was the shortest.

Row spacing had no effect on sugar content, juice yield and potential ethanol yield (Table 2). Similar results for row spacings were reported for sugar content by Kaushik and Shaktawat (2005) and Wortmann et al. (2010). However, the row spacing influenced grain and green stalk yield. Row spacing of 60 cm increased grain (12%) and green stalk (11%) yield compared to 45 cm spacing. Similarly, Broadhead and Freeman (1980) reported greatest stalk yield in row spacing of 52.5 cm. Kaushik and Shaktawat (2005) also recorded maximum grain yield of sorghum with 60 cm row spacing. Wider row spacing of 50–60 cm acts as fallow, which creates bare areas between rows that accumulate and store water early in the crop cycle and help in improving yield.

Nitrogen application had significant effect on sugar content, green stalk yield, juice yield and potential ethanol yield (Table 2). With the application of 90 kg N ha^{-1}, sugar content, green stalk yield, juice yield and potential ethanol yield were increased by 27%, 35%, 38% and 56%, respectively over the control. 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 by Pholsen and Sornsungnoen (2004), Almodares et al. (2007), Gutte et al. (2008), Kumar et al. (2008), Poornima et al. (2008) and Ratnavathi et al. (2010). Since sweet sorghum juice is extracted from green stalk, the highest green stalk yield produces the highest juice yield. A strong correlation between green stalk yield and juice yield ($r = 0.94$) clearly indicates a linear relationship between green stalk and juice yield. This is in conformity to the findings of Kumar et al. (2008) and Ratnavathi et al. (2010).

N fertilizer had profound linear effect on grain yield up to 90 kg ha^{-1} but, further increased N level did not improve grain yield proportionately. The increase in grain yield with 90 kg N ha^{-1} over 0, 30 and 60 kg N ha^{-1} was 36, 26 and 14%, respectively which indicates a diminishing increase in grain yield per each additional unit of N.

Significant differences among the three genotypes were found for sugar content, total green stalk yield, juice yield, potential ethanol yield and grain yield. Hybrid CSH 22 SS was superior in these attributes compared to NTJ 2 and ICSV 93046. CSH 22 SS produced 16 and 13% greater green stalk and grain yield than ICSV 93046 and 28 and 27% than NTJ 2, respectively. These results are in accordance with the findings that hybrids have significant heterosis (30–40%) compared to varieties for cane, juice and sugar yields (Reddy, 2013). Most of the interactions in pooled analysis were insignificant.

3.2. Economics

Row spacings did not significantly affect economic parameters under study, but N level significantly affected the economic parameters (Table 2). Significantly higher economic returns and benefit cost ratio (B:C) were obtained with the application of 90 kg N ha^{-1}, however, further increase in N level up to 120 and 150 kg ha^{-1} did not reflect proportionate increase in these parameters. Application of 90 kg N ha^{-1} had 50, 35 and 18% increases in net returns compared to 0, 30 and 60 kg N ha^{-1}, respectively. Similarly, Uchino et al. (2012) reported that the net income, as estimated from cane fresh weight and grain dry weight, increased with increase in N rates up to 90 kg N ha^{-1}. Further increase in N rates did not significantly affect productivity or income, but instead caused severe lodging at harvest in the plots with 150 kg N ha^{-1}. Among the genotypes, maximum net returns of US$ 681 ha^{-1} and the highest B:C ratio of 3.14 was obtained with CSH 22 SS. Increase in net returns with CSH 22 SS compared to ICSV 93046 and NTJ 2 was 21 and 39%, respectively. Interaction effects for all the treatments were insignificant. This increased net return and B:C ratio with hybrid CSH 22 SS compared

Table 2
Combined analysis of post rainy sweet sorghum cultivars evaluated in India (Pooled of 2008, 2009, 2010).

Treatment	Plant height (cm)	No. of leaves plant^{-1}	Brix (%)	Green stalk yield (Mg ha^{-1})	Juice yield (Mg ha^{-1})	Potential ethanol yield (l ha^{-1})	Grain yield (Mg ha^{-1})	Gross income (US$ ha^{-1})	Net Economic Returns (US$ ha^{-1})	Benefit: Cost Ratio
Row spacing (cm)										
60	186.96	11.11	13.90	41.11	14.52	1000.0	2.14	906.80	598.00	2.88
45	185.89	11.20	13.17	36.62	13.02	842.0	1.89	803.55	492.00	2.54
LSD (5%)	N.S.	N.S.	N.S.	3.3	N.S.	N.S.	0.11	N.S.	N.S.	N.S.
Nitrogen Levels (kg ha^{-1})										
0	170.33	10.73	10.77	28.03	9.70	495.0	1.47	617.14	320.00	2.05
30	176.60	10.74	12.27	32.37	11.34	663.0	1.69	713.08	417.00	2.33
60	183.73	11.03	13.25	37.50	13.43	859.0	1.97	832.05	523.00	2.67
90	192.17	11.68	14.81	43.08	15.60	1114.0	2.28	954.13	640.00	3.01
120	196.33	11.33	15.06	45.31	16.11	1183.0	2.33	996.89	677.00	3.09
150	199.33	11.41	15.11	46.85	16.43	1211.0	2.37	1018.09	693.00	3.10
LSD (5%)	11.91	0.4	0.59	2.87	1.35	144.4	0.09	65.70	58.80	0.10
Genotypes										
CSH 22 SS	201.53	11.63	14.30	45.48	16.20	1125.0	2.33	992.00	681.00	3.14
ICSV 93046	188.40	11.23	13.60	38.44	13.55	905.0	2.03	851.00	539.00	2.70
NTJ 2	169.33	10.6	12.75	32.66	11.56	732.0	1.70	723.00	415.00	2.28
LSD (5%)	16.15	0.16	0.23	3.02	1.01	60.0	0.14	61.40	62.60	0.17
Mean	186.42	11.15	13.54	38.86	13.77	921.0	2.02	855.00	545.00	2.71

to varieties are consistent with earlier reports (Reddy, 2006; Miri and Rana, 2012).

3.3. Nitrogen response

The coefficients of variables in the equations for N response curves (Fig. 1) clearly indicated that the N level has positive linear relationship with both total biomass yield and potential ethanol yield. However at the same time, quadratic terms have negative coefficients. This is a typical case of production function representing law of diminishing returns. Increase in input may increase the output, but after optimal point, output decreases with per unit increase in input. Similar trends for N response of sweet sorghum were reported by Wiedenfeld (1984) and Tamang et al. (2011). Marginal product (MP) curves for biomass yield and ethanol yield are presented in Fig. 1A and B, respectively. An increasing trend in MP was observed from 30 to 90 kg N ha^{-1}. At 90 kg N ha^{-1}; MP was the highest among the five N levels. Beyond 90 kg N ha^{-1}, a sharp decrease in MP indicated that high N application was not profitable. Based on this analysis, an optimum N application rate of 90 kg ha^{-1} is recommended. Similar results were also reported by Erickson et al. (2012) and Tamang et al. (2011). Nitrogen use efficiency values were estimated relative to yield observed in controlled plot, so that NUE values in Fig. 2 represent increment in gross income per unit addition of N fertilizer. A general trend indicated that NUE increased with N application rate up to 90 kg ha^{-1} and then NUE decreased as N application rate increased.

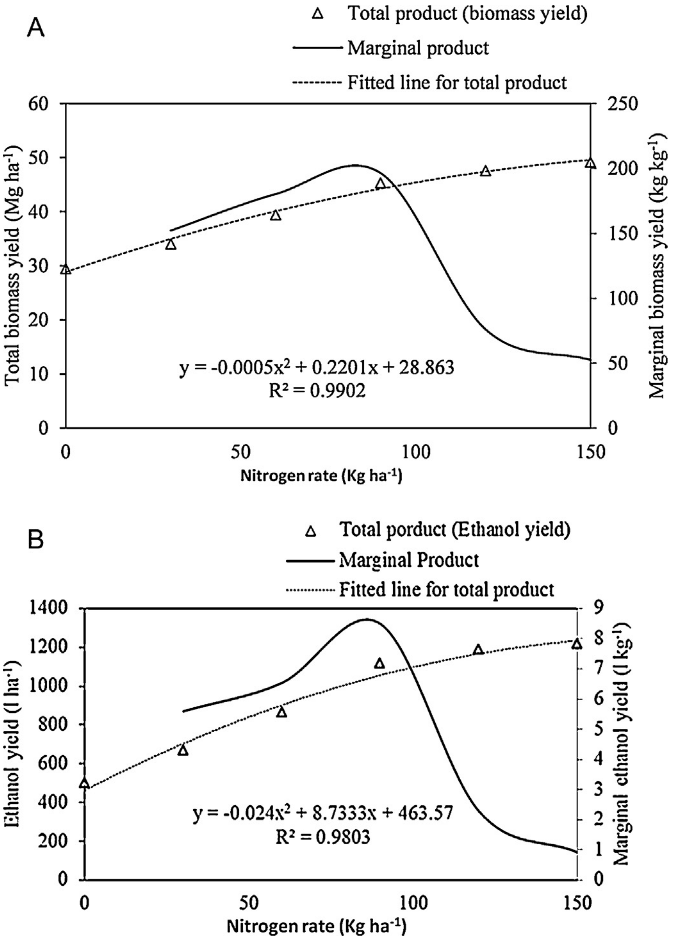

Fig. 1. (A) Effects of nitrogen fertilizer on total and marginal biomass yield. (B) Effects of nitrogen fertilizer on potential total and marginal ethanol yield.

3.4. Water balance component

Soil water balance simulation was carried out for the three growing seasons. Simulation results for the 2008–09 season are shown in Fig. 3A. Results indicated that even after irrigation, crop suffered due to water stress as the available soil moisture depleted below the limit of readily available water which in turn led to

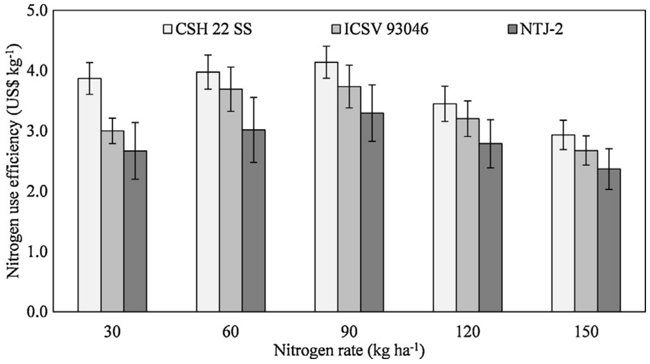

Fig. 2. Effects of genotypes and nitrogen fertilizer on nitrogen use efficiency (economical value of total biomass per unit kilograms of nitrogen fertilizer).

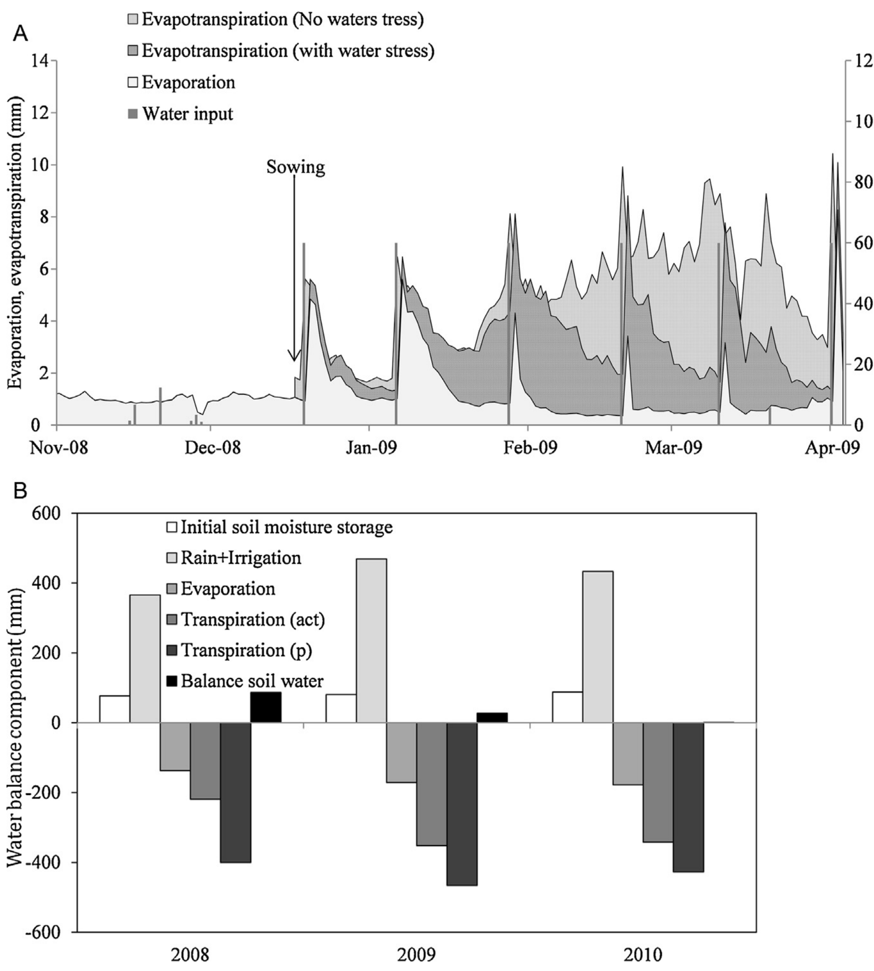

Fig. 3. (A) Simulated daily water balance components during 2008–09 growing season. ETcp and ETca are evapotranspiration with and without water stress and water input = irrigation + rainfall. Date of sowing: 19 December 2008. (B) Simulated total water balance components during crop growing period for 2008, 2009, and 2010.

reduction in evapotranspiration (Fig. 3A). During the wet period (irrigation or rainfall event), evaporation was the major component of evapotranspiration, whereas during the dry period, (no rainfall/irrigation), transpiration component was prominant.

Apart from water availability, transpiration is also affected by temperature, humidity, wind speed, solar radiation, and sunshine hours. The maximum temperature, solar radiation, and sunshine hours between 40 to 50 DAS and 70 to 90 DAS in 2008 were greater than in those 2009 and 2010. Such variation may induce the changes in potential transpiration and thus water requirements. In any case, the reduction in transpiration may have led to lower yield (Berenguer and Faci, 2001) in 2008 as compared to in 2009 and 2010.

Total quantity of simulated water balance components for 2008, 2009 and 2010 are shown in Fig. 3B. Rainfall received during *kharif* season of 2008, 2009 and 2010 was 842, 902, 1091 mm. Estimated values of available soil moisture in top 120 cm soil profile at sowing and harvest were 75, 86, 103 mm and 86, 32, 19 mm, respectively during 2008, 2009 and 2010 (Fig. 3B). Rainfall during the post rainy season and residual moisture in soil may not be sufficient to fulfill water requirement of crop. Thus, 6, 7 and 7 number of supplementary irrigations of 60 mm depth was provided at regular intervals during 2008, 2009 and 2010, respectively. However, depletion of available soil water due to evapotranspiration induced water stress condition. Total reduction in transpiration as a result of water stress was about 45, 24 and 20% during 2008, 2009 and 2010, respectively. Yield response of various crops to water stress has been documented by Steduto et al. (2012).

3.5. Water use efficiency

Water use efficiency values were estimated using total water input (initial available moisture + rainfall + irrigation) (Fig. 4). For N dose of 90 kg ha^{-1}, CSH 22 SS showed the highest economic return per unit volume of water usage (US$ 0.22 m^{-3}). Water use efficiency values for CSH 22 SS, ICSV 93046 and NTJ 2 were in the range of US$ 0.13–0.23, 0.10–0.21, and 0.09–0.18 per cubic meter of water, respectively. Water use efficiency for 60 cm row spacing was 5–27% more than the 45 cm row spacing, however, greater differences were observed for low N dose. Water use efficiency

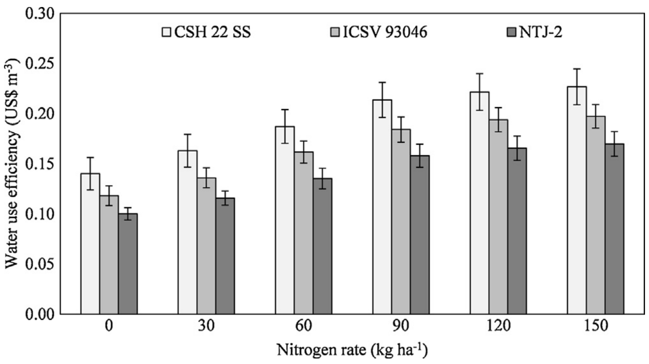

Fig. 4. Effects of genotypes and nitrogen fertilizer treatments on water use efficiency (economical value of total biomass per unit water depth) with respect to total water input.

values with respect to total transpiration were 66% greater compared to total water input. Effect of row spacing on water uptake was not considered in soil water balance simulations. As increase in plant population increased the water uptake and reduced evaporation losses (Stickler and Laude, 1960), higher water requirement might have increased water stress in narrow row spacing (45 cm), which in turn affected crop growth and yield parameters (Table 2). Berenguer and Faci (2001) reported that low plant population resulted in greater tiller production, number of grains per panicle and higher weight of grain, which would compensate for the lower number of plants. Thus, a high plant density may not be associated with productive advantages in the yield.

Physical water use efficiency with respect to total biomass of sweet sorghum and total water input was in the range of 3.8–15.6 kg m^{-3} with an average of 8.3 kg m^{-3}, and these values are greater than that of the WUE values reported by other researchers (Steiner, 1986; Mastrorilli et al., 1999; Patil, 2007; Wani et al., 2012). In comparison to sweet sorghum, water productivity of sugarcane is in the range of 3.8–18.4 kg m^{-3} (Thompson, 1976; Robertson and Muchow, 1994; Kingston, 1994; Olivier and Singels, 2003; Bahrani et al., 2008; Wiedenfeld and Enciso, 2008). However, total water requirement of sugarcane can be three times more than that of two crops of sorghum. Thus, sweet sorghum, because of its high fermentable sugars, low fertilizer requirement, high water use efficiency, short growing period and the ability to adapt well to diverse climate and soil conditions, is a smart feedstock for bioethanol production and sustainable option as energy crop.

4. Conclusion

A three- year field experiment was conducted on Vertisols of the semi-arid region of India to evaluate the performance of three sweet sorghum genotypes (CSH 22 SS, ICSV 93046, and NTJ 2) with two row spacings (60 cm and 45 cm) and six N levels (0, 30, 60, 90, 120, and 150 kg ha^{-1}) under irrigation in the post rainy seasons of 2008, 2009 and 2010. The data showed that plant growth and yield parameters of hybrid CSH 22 SS were significantly superior to those of ICSV 93046 and NTJ 2. CSH 22 SS showed higher green stalk and grain yield by 16 and 13% over ICSV 93046 and 28 and 27% over NTJ 2, respectively. While spacing did not have significant influence on vegetative parameters, effect of N levels was observed for all three genotypes. Increase in N levels also showed increase in yield, but beyond 90 kg N ha^{-1}, the relative increase in yield was lower. Economic analysis also suggested greater net returns from CSH 22 SS at N level of 90 kg ha^{-1}. Similar trend was noticed for estimated NUE. Soil water balance simulations indicated that the total transpiration during crop growth period might be reduced by 45, 24 and 20% in 2008, 2009 and 2010, respectively as compared to potential transpiration. In case of WUE, CSH 22 SS showed highest economic returns per unit volume of water usage confirming that sweet sorghum is a smart biofuel crop to be grown in semi arid tropics with limited water availability. Thus, based on observations and estimated resource use efficiency values, we conclude that hybrid CSH 22 SS with N fertilizer dose of 90 kg ha^{-1} and row spacing of 60 cm is more economical and remunerative practice.

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