Standardization of nitrogen fertilizer rate for sugar yield optimization in sweet sorghum

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Introduction

The recent skyrocketing of global fossil fuel prices driven by shrinking supplies in the face of rising demand and increased concerns over environmental pollution associated with fossil fuel use triggered tremendous efforts in exploring the use of alternative renewable fuel sources particularly the transportation fuels worldwide. Ethanol is the *numero uno* biofuels currently produced mainly from maize (*Zea mays*) and sugarcane (*Saccharum officinarum*). Sweet sorghum (*Sorghum bicolor*) is similar to grain sorghum, having fast growth, high biomass production and wider adaptability and is known to have great potential in ethanol production (Reddy et al. 2005). There is an increased interest in the utilization of sweet sorghum for ethanol production in India, the Philippines, China and USA, as its growing period (about 4 months) and water requirement (8000 m^3 over two crops) (Soltani and Almodares 1994) are 4 times lower than those of sugarcane (12–16 months and 36,000 m^3 $crop^{-1}$, respectively). To make sweet sorghum a sustainable and profitable crop, there is a need for standardization of agronomic practices, apart from breeding high-yielding cultivars, which can contribute to increased yields resulting in higher returns to farmers. Application of fertilizers has a direct impact on crop productivity. Nitrogen (N) is one of the major nutrients that support crop growth and is the most responsive nutrient required by sorghum (Singh et al. 1972). The present study was conducted at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India to standardize the optimum N dosage for the optimization of sugar yields in sweet sorghum.

Materials and methods

Five sorghum genotypes (a hybrid – ICSA 475 × E 36-1 and 4 varieties – SPV 422, PVK 801, ICSR 89068 and NTJ 2) were evaluated during 2006 postrainy and 2007 rainy seasons for their response to varying N fertilizer levels. The experiment was laid out in a strip plot design with four replications. Each plot consisted of a genotype grown in 4 rows, each of 4 m length. A spacing of 75 cm between rows and 12 cm between plants in a row was maintained. The black soils at the test location were found to have total N content (486 ppm) below critical limits (lower level: 500–1200 ppm; medium level: 1200–2500 ppm; and higher level: >2500 ppm). The average levels for other nutrients were also recorded. The P (phosphorus) content was 3.8 ppm (critical levels – lower level: <5 ppm; medium level: 5–10 ppm; and higher level: >10 ppm), K (potassium) content was 204 ppm (critical levels – lower level: <50 ppm; medium level: 50–125 ppm; and higher level: >125 ppm), S (sulfur) content was 6.5 ppm (critical limit: 8–10 ppm), Fe (iron) content was 0.25 ppm (critical limit: 2 ppm) and Zn (zinc) content was 0.40 ppm (critical limit: 0.75 ppm). The treatments included four N levels and uniform levels of P for all the treatments:

- T1 – no fertilizer applied: 0 kg N ha^{-1} and 28 kg P_2O_5 ha^{-1};
- T2 – basal: 18 kg N ha^{-1} and 28 kg P_2O_5 ha^{-1};
- T3 – basal + 1 topdressing: 64 kg N ha^{-1} and 28 kg P_2O_5 ha^{-1} (basal – 18 kg N ha^{-1}, topdressing – 46 kg N ha^{-1});
- T4 – basal + 2 topdressings: 110 kg N ha^{-1} and 28 kg P_2O_5 ha^{-1} (basal – 18 kg N ha^{-1}, topdressing – 46 + 46 kg N ha^{-1}).

Data were recorded for agronomic parameters (time to 50% flowering, plant height, plant agronomic performance, biomass, lodging, stay green and grain yield) and juice-related traits at flowering and maturity [fresh stalk yield, cane yield, juice yield, juice volume, bagasse, soluble solid concentration (°Bx) and sugar yield]. Data was analyzed using Genstat 10th edition and the results on selected traits are reported here.

Results and discussion

Combined analysis of variance depicted that the growing season had significant influence on all the sweet stalk traits (Table 1). The treatments (N levels) had significant influence on time to 50% flowering, cane yield, juice volume, sugar yield and grain yield, while plant height and soluble solid concentration (°Bx) was not influenced by N level. Similarly, the first order interaction between season and treatment was significant for all the traits except plant height and °Bx. It clearly showed that irrespective of season, plant height and °Bx were not influenced by the application of different rates of N fertilizer.

Table 1. Combined analysis of variance of sweet sorghum genotypes across varying nitrogen fertilizer levels during 2006 postrainy and 2007 rainy seasons at ICRISAT, Patancheru, India[1].

Source of variation	df	Time to 50% flowering (days)	Plant height (m)	Cane yield (t ha^{-1})	Juice volume (kl ha^{-1})	Soluble solid concentration (°Bx)	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
Season	1	140.62**	17.56**	33260.87**	6554.53**	270.95**	411.03**	766.01**
Residual	6	5.492	0.114	95.28	31.85	2.242	0.5718	8.131
Treatment	3	78.242**	0.022	762.35**	206.02**	1.675	4.66**	17.87**
Season × Treatment	3	36.775**	0.061	297.53**	45.25**	2.112	1.31*	23.01**
Residual	18	4.864	0.025	30.07	8.02	1.146	0.3417	2.752
Genotype	4	1207.9**	6.676**	5398.04**	1249.77**	133.75**	46.93**	34.097**
Season × Genotype	4	408.15**	0.693**	1194.45**	215.31**	70.80**	12.84**	32.189**
Treatment × Genotype	12	6.762	0.031	137.59**	37.92**	1.101	1.07*	3.779**
Season × Treatment × Genotype	11	4.431	0.05	56.17	16.13	1.972	0.6927	4.197**
Residual	91	3.63	0.034	48.21	15.82	1.616	0.5239	1.384

1. * = Significant at 5% level; ** = Significant at 1% level.

Table 2. Analysis of variance of sweet sorghum genotypes across varying nitrogen fertilizer levels during 2007 rainy season at ICRISAT, Patancheru, India[1].

Source	df	Time to 50% flowering (days)	Plant height (m)	Cane yield (t ha^{-1})	Juice volume (kl ha^{-1})	Soluble solid concentration (°Bx)	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
Replication	3	4.9	0.078	102.14	17.29	0.623	0.8366	2.447
Replication × Treatment stratum								
Treatment	3	109.23**	0.007	1001.21**	220.41**	2.784	5.44**	7.18**
Residual	9	1.64**	0.036	52.64	14.29	1.647	0.647	0.838
Replication × Treatment × Genotype stratum								
Genotype	4	1083.25**	5.78**	5713.74**	1214.05**	53.38**	52.88**	46.13**
Treatment × Genotype	12	6.65**	0.068	171.76*	44.27	1.256	1.5756	1.262
Residual	48	2	0.055	87.21	27.13	1.693	0.9765	1.054

1. * = Significant at 5% level; ** = Significant at 1% level.

Table 3. Mean performance of sweet sorghum genotypes for sugar yield across varying nitrogen fertilizer levels during 2007 rainy season at ICRISAT, Patancheru, India.

Treatment	Sugar yield (t ha^{-1})
No fertilizer (T1)	3.58
Low fertility (basal) (T2)	3.71
Medium fertility (basal + 1 topdressing) (T3)	4.38
High fertility (basal + 2 topdressings) (T4)	4.66
LSD (5%)	0.58

There were significant differences among the genotypes for all the traits, indicating significant genetic variability among them. The interaction between season and genotype was significant, indicating photosensitive nature of sweet sorghum genotypes. Genotype interacted significantly with the treatment for cane yield, juice volume, sugar yield and grain yield but the interaction was not significant for time to 50% flowering, plant height and °Bx. Second order interactions between season, treatment and genotype were significant for grain yield and not significant for the rest of the traits (time to 50% flowering, plant height, cane yield, juice volume, °Bx and sugar yield). Grain yield of sweet sorghum cultivars was influenced by treatment, season and season × treatment interactions and these effects are genotype specific.

From the combined ANOVA, it can be concluded that for sugar yield, differential treatment effects were significant. However, the variations among the treatments were also attributed to the interaction with seasons and genotypes. Due to significant influence of season, the results are presented season-wise.

Nitrogenous fertilizer effects during rainy season. Significant influence of treatments was observed for the traits time to 50% flowering, cane yield, juice volume, sugar yield and grain yield. However, effects of treatment were genotype specific for the traits time to 50% flowering and cane yield (Table 2). Sugar yield increased with increase in the rates of N. T1 was on par with T2 while T3 was on par with T4, and T3 and T4 were

Table 4. Analysis of variance of sweet sorghum genotypes across varying nitrogen fertilizer levels during 2006 postrainy season, ICRISAT, Patancheru, India[1].

Source	df	Time to 50% flowering (days)	Plant height (m)	Soluble solid concentration (°Bx)	Cane yield (t ha^{-1})	Juice volume (kl ha^{-1})	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
Replication	3	6.083	0.14979	3.86	88.432	46.401	0.30708	13.815
Replication × treatment stratum								
Treatment	3	5.783	0.08*	1.003	58.66**	30.86**	0.52**	33.7**
Residual	9	8.083	0.01	0.645	7.505	1.74	0.03648	4.666
Replication × Treatment × Genotype stratum								
Genotype	4	532.84**	1.59**	151.18**	878.755**	251.02**	6.9**	20.16**
Treatment × Genotype	12	4.544	0.01	1.817	22.006**	9.78*	0.19**	6.72**
Residual	48	5.26	0.01	1.537	8.354	4.262	0.06156	1.72

1. * = Significant at 5% level; ** = Significant at 1% level.

Table 5. Mean performance of sweet sorghum genotypes for sugar yield and grain yield across varying nitrogen fertilizer levels during 2006 postrainy season at ICRISAT, Patancheru, India.

Treatment	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
No fertilizer (T1)	0.734	5.98
Low fertility (basal) (T2)	0.747	5.85
Medium fertility (basal + 1 topdressing) (T3)	0.993	5.98
High fertility (basal + 2 topdressings) (T4)	1.043	8.53
LSD (5%)	0.14	1.55

Table 6. Mean performance of five sweet sorghum genotypes for sugar yield (t ha^{-1}) across varying nitrogen fertilizer levels during 2006 postrainy season at ICRISAT, Patancheru, India.

Treatment	NTJ 2	SPV 422	PVK 801	ICSR 89068	ICSA 475 × E 36-1
No fertilizer (T1)	1.218	1.052	0.586	0.754	1.141
Low fertility (basal) (T2)	1.244	1.221	0.563	0.694	1.331
Medium fertility (basal + 1 topdressing) (T3)	1.383	1.503	0.919	0.824	1.33
High fertility (basal + 2 topdressings) (T4)	1.262	1.516	0.794	0.609	1.082
LSD (5%)	0.33	0.33	0.33	0.33	0.33

significantly superior over T1 and T2 for sugar yield, indicating that basal + one topdressing (64 kg N ha^{-1}) is sufficient to obtain maximum sugar yield at maturity, and thereafter responses to further application of nitrogenous fertilizer were not significant (Table 3). Similar results were observed by Sumantri and Lestari (1997), who recorded incremental increase in stalk yield up to 90 kg N ha^{-1} in an experiment where a maximum rate up to 120 kg N ha^{-1} was applied. Similarly, Coutinho et al. (1988) observed that cane and ethanol yields increased with application of up to 100 kg N ha^{-1}.

Nitrogenous fertilizer effects during postrainy season. Fertilizer effects were also significant for the traits plant height, cane yield, juice volume, sugar yield and grain yield denoting that the genotypes responded significantly to different N fertilizer levels for these traits. But the response was not significant for time to 50% flowering and °Bx. However, response of different genotypes to varying N fertilizer levels varied for sugar yield as seen by the significant fertilizer × genotype interaction effects (Table 4). As in rainy season, T1 was on par with T2 and T3 was on par with T4 for sugar yield, indicating that basal + one topdressing is sufficient to obtain maximum sugar yield at maturity (Table 5). However, for most of the genotypes tested, T3 treatment was superior over the rest in realizing maximum sugar yield (Table 6).

Based on the results of two seasons, it can be concluded that for obtaining maximum sugar yields in sweet sorghum, an optimum dosage of 64 N ha^{-1} (half as basal and half as topdressing) can be applied.

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