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Research Paper

Production potential of sweet sorghum (*Sorghum bicolor*) for biomass, grain yield and bio-fuel under variable nutrient environment in north-west India

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ABSTRACT

A field experiment was conducted at the fodder research farm of the Punjab Agricultural University, Ludhiana, during the rainy (*kharif*) seasons of 2019 and 2020, to assess the relative performance of sweet sorghum [*Sorghum bicolor* (L.) Moench] genotypes under different fertility levels. Three sweet sorghum genotypes tested were: 'SPV 2530', 'CSV 19SS' and 'CSV 24SS' at 3 fertility levels, i.e. 60 : 30 : 30, 80 : 40 : 40 and 100 : 50 : 50 kg N : P_2O_5 : K_2O/ha. All the treatment combinations were replicated thrice in a factorial randomized block design. The variations in terms of growth and ethanol yield were observed among 3 genotypes, with the sweet sorghum genotype 'CSV 19SS' having the best performance, especially in ethanol yield and gave significantly highest potential ethanol yield of 1,490 L/ha. The application of 100 : 50 : 50 kg N:P:K/ha resulted in the best growth response and recorded significantly maximum ethanol yield of 1,417 L/ha. However, fertilizer rate as low as 80 : 40 : 40 kg N : P : K/ha produced potential ethanol yield which was statistically at par as produced with the highest fertility level. Hence, 80 : 40 : 40 kg N : P : K/ha would also result in reasonable performance of the crop in the areas of this study, especially under favourable environmental conditions.

Key words: Ethanol yield, Fertility levels, Genotypes, Juice yield, Sweet sorghum

Sweet sorghum rich in fermentable sugars can be considered as an important feedstock for bio-ethanol production. It has both readily fermentable sugar-based (i.e., sucrose, glucose, and fructose) and cellulosic-based (i.e., starch, hemicellulose, and cellulose) ethanol product (Singh *et al*., 2015). It is an annual energy crop that favorably answers the "food or fuel" question as it does not compete with food or feed, and it can ratoon, following harvest, under favorable climatic conditions. These features have made sweet sorghum a choice bio-ethanol crop of the semi-arid tropics in the sub-Saharan Africa and India (Borghi *et al*., 2013). It is a crop of high universal value since it can be cultivated in tropical, subtropical, temperate, and semi-arid regions, as well as in poor quality soils of the world.

In India, sweet sorghum is encouraged for fuel production and lately many new genotypes of sweet sorghum have been developed for bio-fuel purpose. These genotypes generally differ with respect to their production potential, adaptation, duration and in their response to fertilization under different agro-ecological regions (Miri and Rana, 2012). For bio-fuel production, genotypes with high fresh stalk yield, juice-extraction percentage, brix value are preferably desired. Therefore, the choice of genotypes is very essential in order to secure high biomass, sugar and ethanol from sweet sorghum crop.

With the development and release of high-yielding genotypes, the important management practice which needs adoption, particularly by the farmers, is fertilization in order to achieve the full yield potential of such genotypes (Bhavani *et al*., 2021). An appropriate fertilization practice is important in obtaining high biomass yields of bio-energy crops and subsequently high bio-fuel yields. Nitrogen fertilizer promotes sucrose content, protein per cent, growth rate and quality parameters in sweet sorghum (Mishra *et al*., 2015). The research towards major area of interventions, particularly on sweet sorghum variety development and fertilization strategies, has been limited in Punjab in India. Nutrient demand of sweet sorghum genotypes generally varies in different agro-ecological regions. Hence, for the viability of sweet sorghum as a source of renewable energy, it is essential to not only breed high-yielding varieties, but also develop and establish appropriate agronomic practices, including the use of optimum level of fertilizers. This study was therefore carried out to find out the suitable genotype and optimum fertility level

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for higher productivity and profitability of sweet sorghum in Punjab.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) seasons of 2019 and 2020 at the Punjab Agricultural University, Ludhiana (30°54' N, 75°48' E, 247 m above mean sea-level) in the central plain region of Punjab state under Trans-Gangetic agro-climatic zone of India. The climate of Ludhiana is subtropical and semi-arid. The average annual rainfall is 705 mm. Ludhiana soil is classified as Inceptisols, well-drained sandy loam, with an average *p*H of 7.8, available nitrogen 184 kg/ha, phosphorus 16.8 kg/ha and potassium 246 kg/ha.

A factorial randomized complete-block design was used to evaluate the performance of sweet sorghum genotypes for growth, yield and ethanol production under different fertility regimes. The treatments thus comprised combinations of 3 sweet sorghum genotypes ('SPV 2530', 'CSV 19SS' and 'CSV 24SS') and 3 fertility levels (60: 30 : 30; 80 : 40 : 40; and 100 : 50 : 50 kg N : P_2O_5 : K_2O/ha), and each treatment was replicated thrice. Each plot consisted of 4 crop rows of 5 m length, with row spacing of 60 cm. Sowing was done in mid-July and seeds were planted in furrows and plants were thinned to 15 cm apart. As per the treatments, half dose of nitrogen through urea and full dose of phosphorus in the form of single superphosphate and potassium as muriate of potash were applied basal. The remaining nitrogen was applied 35 days after sowing. Two hand-weedings were done at 20 and 40 days after sowing to keep the crop weed-free. Other management practices were adopted as per recommendations of sorghum crop.

At physiological maturity, data on plant population and plant height were collected. Further, at physiological maturity, 10 plants from the central sample row of each plot were cut close to the ground for measuring fresh millable stalk yield and biomass. 10 whole plants (leaves, stalks and panicles) were weighed immediately and fresh biomass was recorded. Then the leaves along with sheath were stripped and panicle was separated to measure the fresh stalk weight. The stalk juice was extracted with a sugarcane crusher and weighed to determine the juice yield. Extraction per cent refers to the actual amount of juice extracted from known weight of the stripped stalk and expressed as per cent of extraction. The brix in the cane was determined using refractometer (Hanna instruments). Potential ethanol yield per hectare was obtained as:

$$\text{Potential ethanol yield (L/ha)} = \frac{\text{Juice yield (L/ha)} \times \text{Sugar content (brix \%)}}{100} \times \frac{0.85}{1.76}$$

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

Plant height, panicles/m^2 and panicle length were recorded at the time of harvesting by following standard procedures. Grain yield was recorded after thorough sun-drying of the panicles. Economics of sweet sorghum under different treatments was computed by taking the prevailing local market price.

The data were analyzed according to Fisher's technique of Analysis of Variance (ANOVA). The differences between treatments were tested by the least significant difference at a 5% level of probability when ANOVA was significant.

RESULTS AND DISCUSSION

Days to 50% flowering differed significantly due to genotypes and fertility levels. The sweet sorghum genotype 'CSV 19SS' took the maximum days to 50% flowering (80 days), while the other 2 genotypes were at par with each other. Differential phenology of sweet sorghum genotypes was also reported by Rao *et al*. (2013). Increase in fertility levels reduced the number of days required for 50% flowering and the crop receiving the application of 100 : 50 : 50 kg N:P:K/ha flowered 7 days earlier than the crop receiving 60 : 30 : 30 kg N:P:K/ha (Table 1). The environmental stress manifested as low nutrient availability generally delays the onset of the reproductive stage as observed in the present study. These results agree with those obtained by Mishra *et al*. (2015), who reported that low fertility delayed the growth and development of sweet sorghum. However, days to maturity or grain-filling did not differ significantly due to genotypes or fertility levels.

Plant population at harvesting varied significantly among the genotypes and the highest number of plants/ha was recorded in the sweet sorghum genotype 'CSV 19SS' (101,900/ha). Genotype 'CSV 24SS' remained at par with 'CSV 19SS' with respect to plant population. The effect of fertility levels on plant number/ha remained statistically non-significant. Significant variation was recorded in plant height in different sweet sorghum genotypes (Table 1). Tallest plants were recorded by the genotype 'SPV 2530' (291 cm), followed by 'CSV 19SS' (236 cm), and significantly the lowest plant height was seen in the genotype 'CSV 24SS' (212 cm). This variation in growth might be the result of the differences in their genetic combination, inherent variation and vigour. Fertilizer application had a significant positive effect on growth of sweet sorghum. The plant height of sweet sorghum genotypes increased significantly with increasing fertility levels, the maximum being 257 cm with application of 100 : 50 : 50 kg N : P : K/ha. Miri and Rana (2012) also reported variation in plant height in sweet sorghum due to variable fertility levels. Increased availability of nutrients in soil with increase in fertility levels might have enhanced meristematic activity

Table 1. Effect of genotypes and fertility levels on crop phenology and growth of sweet sorghum (pooled data of 2 years)

Treatment	Days to 50% flowering	Days to maturity	Plant population at harvest ('000/ha)	Plant height (cm)
Genotypes				
'SPV 2530'	76	147	75.0	291
'CSV 19SS'	80	150	101.9	236
'CSV 24SS'	75	149	96.9	212
CD (P=0.05)	4	NS	6.6	11
Fertility levels (N : P_2O_5 : K_2O/ha)				
60 : 30 : 30	74	146	89.4	242
80 : 40 : 40	76	149	89.8	249
100 : 50 : 50	81	151	94.4	257
CD (P=0.05)	4	NS	NS	11
Interaction	NS	NS	NS	NS

leading to increased plant height. Moreover, the non-significant interaction between genotypes and fertility levels with respect to plant population and plant height was noted.

Grain yield differed significantly among the genotypes (Table 2). Among the 3 genotypes tested, 'SPV 2530' showed the lowest grain yield potential and recorded 0.66 t/ha grain yield and it was 49.2% lower than that of 'CSV 19SS' and 55.1% lower than that of 'CSV 24SS'. Both 'CSV 19SS' and 'CSV 24SS' genotypes remained at par with each other with respect to grain yield. The genotype 'CSV 24SS' gave the highest grain yield (1.47 t/ha). The highest grain yield observed in 'CSV 24SS' and 'CSV 19SS' than 'SPV 2530' could be associated with more panicles/m^2, grains/panicle and grain weight. With respect to fertility level, the grain yield was found to increase significantly with consecutive increase in fertility. As compared to the application of 60 : 30 : 30 kg N : P : K/ha, the grain yield increased by 11.7% with 80:40:40 kg N:P:K/ha and by 21.4% with 100 : 50 : 50 kg N:P:K/ha. Also, fertility application rate up to 80 : 40 : 40 kg N : P : K/ha had a profound linear effect on the grain yield which implies that, optimum fertilization rate for sweet sorghum is 80 : 40 : 40 kg N:P:K/ha, and further increase in fertilization rate did not increase grain yield proportionately. Increased nitrogen rate in the form of increased fertility levels might have accelerated the conversion of rapidly synthesized carbohydrates (owing to increased N supply) into protein and developed a plant root-system faster, as reported by Dixit *et al*. (2005). This resulted in a stupendous crop growth which was expressed in taller plants, greater biomass yield and consequently higher grain production. The interaction between fertility levels and genotypes for grain yield was not significant.

Fresh stalk yield showed significant differences among the genotypes. The genotype 'CSV 19SS' recorded significantly highest stalk yield (42.1 t/ha) and it was higher by 18.3% over 'CSV 24SS' and by 20.6% over 'SPV 2530'. The genotypes 'SPV 2530' and 'CSV 24SS' remained at par with each other for fresh stalk yield. Crop management is important to attain higher stalk yield in sweet sorghum. Among the various inputs that improve the efficiency of a genotype in realizing its potential, fertilizers (nitrogen in particular) play a crucial role. Significant increase in fresh stalk yield was observed with successive increase in fertility levels. The interactive effect of genotype and fertiliza-

Table 2. Effect of genotypes and fertility levels on yield components and yield of sweet sorghum (pooled data of 2 years)

Treatment	Panicles/m^2	Panicle length (cm)	Grain yield (t/ha)	Fresh stalk yield (t/ha)
Genotypes				
'SPV 2530'	8.1	15.8	0.66	34.9
'CSV 19SS'	12.7	22.8	1.30	42.1
'CSV 24SS'	11.1	19.4	1.47	35.6
CD (P=0.05)	1.0	1.4	0.16	2.1
Fertility levels (N : P_2O_5 : K_2O/ha)				
60 : 30 : 30	9.2	17.5	1.03	31.9
80 : 40 : 40	11.0	19.3	1.15	38.4
100 : 50 : 50	11.6	21.1	1.25	42.3
CD (P=0.05)	1.0	1.4	0.16	2.1
Interaction	NS	NS	NS	NS

tion rate pointed to the fact that, there is variation in the fresh stalk yield responses of the genotypes to the application of fertilizers.

Both genotypes and fertility levels significantly influenced net returns and benefit: cost ratio (Table 3). The highest net returns (₹ 89,111/ha) were obtained by the genotype 'CSV 19SS', being 23.2 and 26.7% more than genotypes 'CSV 24SS' and 'SPV 2530' respectively. Benefit : cost ratio was also higher in 'CSV 19SS'. Since fertilizer is a costly input, its efficient management requires scientifically sound application, so that the maximum returns could be achieved and in the present investigation, the net returns and benefit: cost ratio increased with corresponding increase in fertility levels. The highest net returns (₹ 88,949/ha) and benefit : cost ratio (4.35) were observed in plots treated with 100 : 50 : 50 kg N : P : K/ha; however, its differences with 80 : 40 : 40 kg N : P : K/ha were found to be statistically non-significant.

The data pertaining to interaction effect of genotypes and fertility levels on juice yield of sweet sorghum are presented in Fig. 1. Since the sweet sorghum juice is extracted from the stalk and so juice yield followed the pattern of fresh stalk yield. Hence, higher the stalk yield higher the amount of juice yield. Significant differences among 3 genotypes were found for juice yield, and potential ethanol yield. Among the genotypes, significantly highest juice yield was recorded by 'CSV 19SS' (17,337 L/ha), followed by 'CSV 24SS' (14,549 L/ha). The 3 genotypes exhibited almost a similar juice extraction percentage (38.6–40.5%). Miri and Rana (2012) and Rao *et al*. (2013) also reported variation in juice yield among sweet sorghum genotypes. Further, these results are in accordance with the findings that, hybrids have significant heterosis (30–40%) compared to varieties for stalk, sugar and juice yield (Mishra *et al*., 2015). Juice yield increased significantly with the subsequent increase in fertility levels. The maximum juice yield was recorded with application of 100 : 50 : 50 kg N

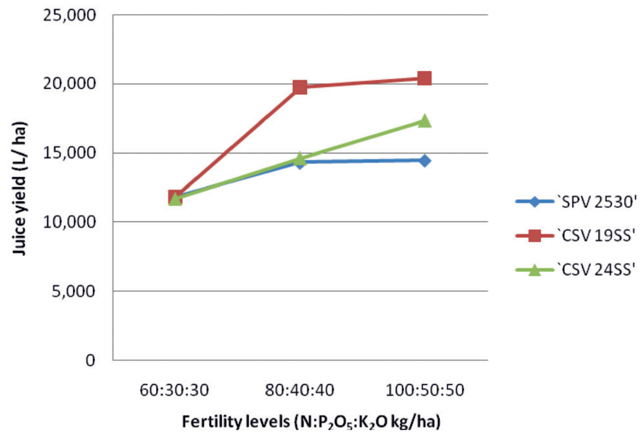

Fig. 1. Interaction effects of sweet sorghum genotypes and fertility levels for juice yield

: P : K/ha and it was higher by 7.3% over 80 : 40 : 40 kg N : P : K/ha and by 47.8% over 60 : 30 : 30 kg N : P : K/ha. This could be due to increase in juice-extraction percentage with increase in fertility. The juice-extraction percentage increased from 35.8 to 42.3% from 60 : 30 : 30 kg N : P : K/ha to 100 : 50 : 50 kg N : P : K/ha.

The value of ethanol yield is a direct result of brix value and the juice yield, which also correlate with the fresh stalk yield of the crop (Almodares *et al*., 2008). The genotype 'CSV 19SS' gave greater estimated ethanol yield, which was the natural effect of brix (%), juice yield and stripped stalk weight (Fig. 2). Potential ethanol yield varied from 1125 ('SPV 2530') to 1490 L/ha ('CSV 19SS'). The effect of fertility levels on potential ethanol yield was similar to that of the juice yield. Increasing fertility levels significantly increased the value of potential ethanol yield. Increase in ethanol yield owing to fertilization in sweet sorghum genotypes was primarily because of the increase in fresh stalk yield, juice yield and sugar concentration. Similar results were also reported by Mishra *et al*. (2015). Most of the interactions in the analysis were non-significant.

Table 3. Effect of genotypes and fertility levels on quality and economics of sweet sorghum (pooled data of 2 years)

Treatment	Brix (%)	Juice extraction (%)	Net returns (× 10^3/ha)	Benefit : cost ratio
Genotypes				
'SPV 2530'	17.3	38.6	70.3	3.73
'CSV 19SS'	18.0	40.5	89.1	4.50
'CSV 24SS'	18.1	40.4	72.3	3.81
CD (P=0.05)	0.7	NS	10.55	0.40
Fertility levels (N : P_2O_5 : K_2O/ha)				
60 : 30 : 30	16.5	35.8	62.9	3.53
80 : 40 : 40	16.8	41.4	79.9	4.15
100 : 50 : 50	20.1	42.3	88.9	4.35
CD (P=0.05)	0.7	3.0	10.55	0.40
Interaction	NS	NS	NS	NS

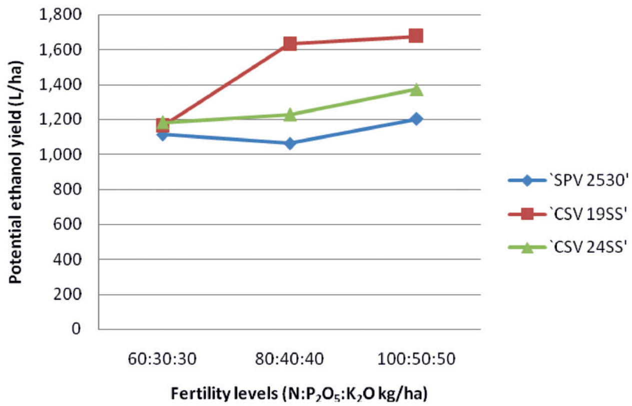

Fig. 2. Interaction effects of sweet sorghum genotypes and fertility levels for potential ethanol yield

Thus, the sweet sorghum genotype 'CSV 19SS' performed superiorly, especially in ethanol yield and therefore, this genotype could be more productive and profitable in northwestern conditions of India. The application of 100 : 50 : 50 kg N: P: K/ha resulted in the best growth response and ethanol yield. However, the fertilizer rate as low as 80 : 40 : 40 kg N: P: K/ha would also result in reasonable performance of the crop in the areas of this study.

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