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Growth and Ethanol Yield Responses of Sweet Sorghum [*Sorghum bicolor* (L.) Moench] Varieties to Nitrogen Fertilizer Rates

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ABSTRACT

Purpose : *Soils of the experimental area are low in vital nutrients such as nitrogen. Fallow is no longer possible because of increasing pressure on arable land. The limited available chemical fertilizers must be inevitably and judiciously used for optimum yield. The study was carried out to assess the response of sweet sorghum varieties to varying nitrogen fertilizer (N) rates.*

Research Method : *Sweet sorghum varieties (NTJ-2, 64 DTN, SW Makarfi 2006 and SW Dansadau 2007) were alloted to the main plots and nitrogen fertilizer (0, 40, 80, 120 and 160 kg N ha^{-1}) to the sub-plots of a split-plot design, in three replicates. Data on growth and yield characteristics were collected and analysed.*

Findings : *Variations were observed among the four varieties of sweet sorghum; SW Dansadau 2007 had greater growth and yield characteristics. N fertilizer had positive effects on the growth characteristics and ethanol yield of the crop. 80 kg N ha^{-1} resulted in increase of most parameters and ethanol yield, beyond which there was either no significant difference or a drop in the values of these parameters. Thus the use of 80 kg N ha^{-1} would result in optimum yield of sweet sorghum in the study area.*

Limitations : *The requirement of 80 kg N ha^{-1} may not be generalized for the entire southern guinea savanna agro-ecological of Nigeria as the study was carried out only in one location.*

Originality/Value : *These findings would assist farmers in the study area identify the most promising sweet sorghum variety and the optimum fertilizer rate for its production.*

Keywords: *ethanol yield, juice yield, nitrogen fertilizer, sweet sorghum*

INTRODUCTION

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is a C4 plant similar to the grain sorghum but for its juice rich sugary stalks that grow rapidly, yielding high biomass (Shoemaker and Bransby, 2010). The crop, like grain sorghum, produces grain which can be harvested for human consumption and animal feed, and the sugary juice in its stalk can be extracted, processed to syrup or fermented to produce ethanol. The bagasse can be used as animal feed or pre-treated, hydrolyzed and fermented to produce second generation ethanol. The starch from the grains may also be fermented to produce ethanol (Mutepe *et al*., 2016). The fermentation of the starch obtained from the grains increases the

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bioethanol yield obtainable per hectare of sweet sorghum planted (Dolciotti *et al*., 1998). Thus the crop is a highly valuable energy crop that has recently been gaining popularity as a major feedstock for commercial bioethanol production because of its numerous advantages over the other bioethanol crops such as sugarcane, corn and sugar beet. These advantages include early maturity, lower water and nutrient requirement, high biomass and alcohol production with its resultant greater income potential (Rao *et al*., 2009; Sami *et al*., 2013). It has also been pointed out that the ethanol produced from sweet sorghum has a superior burning quality, emits less sulphur and has higher octane rating than that obtained from sugarcane which is usually 113 Research Octane Number (RON). That of gasoline is 87 RON (Reddy, 2006; Reddy *et al*., 2007; Bryant and Burbano, 2011).

The native fertility of most Agricultural Soils in Nigeria, and especially in the Southern Guinea Savannah agro-ecological zone, is low and cannot support suitable crop production over a long time without the application of fertilizers, most especially nitrogen (Solubo, 2000). In the past, long fallow periods of between 5 – 10 years were possible to allow for natural restoration of soil fertility. This is no longer possible because of the pressure on arable land occasioned by the need for greater food production and other socioeconomic activities (Buah and Mwinkaara, 2009). Thus nutrient inputs from chemical fertilizers, which are scarce and unaffordable to local subsistence farmers, are required to replace nutrients which are lost during cropping, to maintain a positive nutrient balance for better crop production. The limited available fertilizers must therefore, be used judiciously for optimum yield.

The biomass yields of sweet sorghum have been reported to vary across a range of nitrogen (N) fertilizer rates, cultivars and plant populations. For instance, Wortmann *et al.,* (2010) reported dry stalk yields from 8 to 48 metric ton ha^{-1} across a range of N fertilization rates, cultivars, and plant populations. Soileau and Bradford (1985) measured dry biomass yields ranging from 6 to 18 metric ton ha^{-1} across a range of fertilization and liming treatments. Similarly, Coutinho *et al*.,(1988) observed that sweet sorghum responded positively to the application of N fertilizer in terms of cane and ethanol yields up to 100 kg N ha^{-1}. Other workers such as Reddy *et al*., (2005), Turgut *et al*., (2005) and Uchino *et al*., (2013) have carried out studies on the optimization of nitrogen requirements of sweet sorghum for various environments and soil types. There is however, very little or no information available, especially in the Southern Guinea Savannah Agro-ecological zone of Nigeria, on the effect of N fertilizer on the biomass yields of sweet sorghum. This is because attention is devoted more to cultivating both grain and sweet sorghum types for their grains. The study was therefore, carried out to assess the performances of sweet sorghum varieties, their responses to varying nitrogen fertilizer rates in terms of growth and ethanol yield, and determine the N fertilizer rate required for the optimum ethanol yield of sweet sorghum in a Southern Guinea Savannah agro-ecological zone of Nigeria.

MATERIALS AND METHODS

Study Site and Experimental Design

The study was conducted at the Teaching and Research Farm, Faculty of Agriculture, University of Ilorin, Nigeria, located on latitude 8°29'N and longitude 4°35'E, with an altitude of 310 m above sea level, during the 2014 and 2015 cropping seasons. The experimental site falls within the Southern Guinea Savannah agro-ecological zone of Nigeria. The rainfall in the study area usually begins around April and ends around October/November each year, with an average annual rainfall in the range of 1,000 and 1,540 mm (Adedoyin, 2000). The field in both seasons was cleared, ploughed, harrowed and ridged. The field was thereafter divided into plots each made up of 4 ridges of 3 m long with inter-row spacing of 1 m, representing an area of 12 m^2. The experiment was a 4 × 5 factorial in a randomized complete block design, laid out in split-plot arrangement, and replicated three times. Four (4) sweet sorghum varieties (NTJ–2, 64 DTN, SW Makarfi 2006 and SW Dansadau 2007) obtained from the Institute of Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria, were allotted to the main plots and five (5) levels of nitrogen (N) fertilizer (0, 40, 80, 120 and 160 kg N ha^{-1}) were allotted to the sub-plots, with 0 kg N ha^{-1} as control.

Sowing and Agronomy

Sowing was done directly on the ridges on the 24th May and 8th of June in 2014 and 2015 respectively with an intra-row spacing of 0.25 m at the rate of about 5 seeds per hole. The emerged seedlings were later thinned to two plants per stand to give a plant population of about 80,000 plants per hectare. Weed control was achieved with pre-emergence herbicide, atrazine (500g L^{-1}, active ingredient) at the rate of 5 L ha^{-1}, supplemented with hoeing at eight (8) weeks after sowing (WAS). Nitrogen fertilizer was applied in two equal doses according to the treatment. The first dose of N fertilizer was applied immediately after thinning (3 WAS), in addition to the 40 kg ha^{-1} of phosphorous (P_2O_5) and potassium (K_2O) which were applied to all the plots. The second dose was applied at 8 WAS immediately after hoeing. For the first dose, NPK 20:10:10 compound fertilizer was used for the plots receiving N fertilization; the P_2O_5 and K_2O were supplemented using single super phosphate (SSP) and muriate of potash (MOP), respectively, to make up the required 40 kg ha^{-1}. For the plots without nitrogen fertilization, only SSP and MOP were applied. Urea was used for the second dose and applied to each plot according to the required treatments. Pre-planting soil samples of the top soil (0 – 30 cm) were obtained for physical and chemical analysis.

Sampling and Measurements

Plant height of five randomly selected plants from the inner rows of each plot were measured bi-weekly beginning from 4 to 10 WAS. Leaf area per plant and dry matter yield were obtained at 6 and 10 WAS from the product of the length and breadth of each leaf, and a factor of 0.75 according to Stickler *et al*., (1961) and Moll and Kamprath (1977). Growth indices such as leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), leaf area ratio (LAR) and net assimilation rate (NAR) calculated from the leaf area and the dry matter yield according to Hunt (1978). Yield parameters obtained include fresh stalk yield, dry stalk yield, stalk girth and stalk length. The brix was measured using a handheld refractometer (Bellingham & Stanley Ltd., Tunbridge Wells, UK). The theoretical juice yield (t ha^{-1}) and sugar yield (t ha^{-1}) of the stalks were then calculated according to Tew *et al*., (2008) and Wortmann *et al*., (2010) in the following steps:

$$CSY=(FSY-DSY)\times((Brix)/100)\times0.75,$$

$$JY,80\%\ extracted=[FSY-(DSY-CSY)]\times0.8,$$

$$SY=JY\times((Brix)/100)\times0.75, \qquad (1)$$

where CSY is the conservative sugar yield (g $plant^{-1}$), FSY is fresh stalk yield (g $plant^{-1}$), DSY is dry stalk yield (g $plant^{-1}$), JY is juice yield (g $plant^{-1}$) with 80% extraction efficiency assumed, and SY is sugar yield (g $plant^{-1}$). The sugar concentration of juice was assumed to be 75% of brix value. Ethanol yield was then estimated as a product of sugar yield and a factor, 0.581 (Liska *et al*., 2009; Wortmann *et al*., 2010; Tamang *et al*., 2011; Teetor *et al*., 2011). The results were then converted to yield in tonnes per hectare (t ha^{-1}) and litres per hectare (L ha^{-1}) for juice and ethanol yields respectively.

Statistical Analysis

All data obtained were subjected to analysis of variance using Genstat Discovery 4 statistical package and the means separated using the least significant difference (LSD) at 5% probability level. A regression of the N fertilizer rates and the ethanol yield was performed on the pooled data to determine appropriate N fertilizer rate for optimum ethanol yield in sweet sorghum for the study area (Snedecor and Cochran, 1980; Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Pre-Planting Soil Analysis

The result of the pre-planting soil analysis shows that the soil of the experimental field was loamy sand in texture and low in organic carbon, and major macronutrients such as nitrogen phosphorus and potassium in both years, which is a proof of the suitability of the soil for the experiment (Table 01). Soil organic carbon is said to be critical in determining the response of plants to nitrogen and phosphorus, although there is no clear agreement on the level of soil organic carbon below which response to N and P fertilization does not occur (Bationo *et al*., 2007). The values of the soil organic carbon obtained in both years fall within the range of values that have been earlier reported for the soil of the Southern Guinea savannah agro-ecological zone of Nigeria (Adedoyin, 2000; Jamala and Oke, 2013). The soil pH was 5.4 and 6.2 in 2014 and 2015 respectively indicating a slightly acidic soil. Although these are a little below the recommended range of 6.5 to 7.5 for the optimum performance of the crop, they fall within the pH range of between 5.0 and 8.5 that can be tolerated by the crop (Smith and Frederiksen, 2000; Almodares *et al*., 2008). It has been reported that the yield of sorghum can be significantly affected by a drop in pH. Duncan (1991) demonstrated a reduction in the yield of sorghum by about 19% as the soil pH dropped from 6.6 to 5.0 and continuously decreased by 67% as the pH further dropped to 4.4.

Rainfall of the Experimental Site

Fig. 01 shows that the rainfall in 2015 was lower than the rainfall recorded in the previous year. The total annual rainfall for 2014 was 1,580.1 mm compared to the total rainfall of 1,000.7 mm recorded in 2015. The distribution pattern in 2014 followed the regular bimodal pattern of the study area with peaks in April and September. The total rainfall days were 92 and 64 days for 2014 and 2015 respectively. Rainfall distribution is one of the most critical factors for sustaining crop productivity, especially in rain-fed agriculture. The unavailability of rainfall from season to season has a lot of effect on the soil water that will be made available to the crop, and on the eventual performance of the crop in terms of growth and yield.

Table 01: The physico-chemical characteristics of the soil of the experimental site in the 2014 and 2015 cropping seasons

Parameter	2014	2015
pH (in water)	5.40	6.20
Total N (%)	0.10	0.16
Available P (mg kg^{-1})	3.00	4.51
Exchangeable K (cmol)	0.20	0.52
Exchangeable Ca (cmol)	0.08	1.12
Exchangeable Mg (cmol)	0.34	0.81
Exchangeable Na (cmol)	0.03	0.28
Exchangeable H^{+}+Al (cmol)	0.25	0.21
ECEC (cmol)	0.82	2.94
Organic Carbon (%)	0.96	1.43
Sand (g kg^{-1})	87.60	85.52
Silt (g kg^{-1})	3.10	6.00
Clay (g kg^{-1})	9.30	8.48
Textural class	Loamy sand	

Response of Plant Height to Nitrogen Fertilizer Rates

Significant variations in plant height were observed at almost all the various stages of measurement in both years except at 4 WAP in 2015 (Table 02). It was observed that the varieties SW Makarfi 2006 and SW Dansadau 2007 were significantly taller than the other two varieties, especially towards the later stages of the crop growth in both years. This is in agreement with observations in other studies such as Agung *et al*., (2013) who observed significant variations in plant height among the four sweet sorghum varieties considered in their study. Similar results have been reported by Sawargaonkar *et al.,* (2013) in their studies carried out to assess the variations in growth characteristics of sweet sorghum.The effects of the first dose of N fertilizer application became significant on the plant height from 6 WAS in both years of the present study (Table 02). Although the total soil nitrogen as observed in the pre-planting analysis of the soil of the experimental site was within the moderately low and medium range in the 2014 and 2015, respectively, the native soil nitrogen was possibly high enough to sustain the seedlings through to 6 WAS when marked, differences were observed among the plants in the control plots (0 kg N ha^{-1}) and the plants in the plots that received N fertilizer application. In 2014 when there was a relatively consistent rainfall, plant height increased with increase in nitrogen fertilizer up to 120 kg ha^{-1} at all the measurement periods when significant nitrogen fertilizer effects were observed. This could be attributed to higher level of organic matter decomposition and subsequent nitrogen mineralization occasioned by higher rainfall in 2014 than what was obtained in 2015, with the resultant effect of higher available nitrogen (Qi *et al*., 2011; Abera *et al*., 2012). The interactive effect of variety × N fertilizer observed at 8 WAS in both years point to the fact that there were variations in the responses of the varieties to the application of N fertilizer. Most of the varieties performed better at lower fertilizer rate in 2014 when there was a relatively higher rainfall.

Physiological Response to Nitrogen Fertilizer Rates

The results of this study showed that there was no significant variation among the evaluated varieties in terms of leaf area index (LAI) in 2014 (Table 03). However, in 2015, obvious variations in the LAI of the four varieties were observed, with the variety 64 DTN having the highest value, closely followed by those of NTJ-2 and SW Dansadau 2007 respectively. Possibly, this may be due to the reduced rainfall in 2015, thereby suggesting an indication that the variety 64 DTN, apart from its broad leaf characteristic, may also possess higher drought stress resistant ability. This assertion is in line with the earlier observations of Rad *et al*., (2011) and Bouazzama *et al*., (2012) who demonstrated positive relationships between the LAI and soil moisture content whereby LAI increased with increases in soil moisture contents. Singh *et al*., (2014) reported an increase in the leaf area index of sweet sorghum with increase in N fertilizer application. The interactive effect of variety × N fertilizer observed in 2015 is an indication that the crop's LAI response was affected by environmental factors such as water and nitrogen. Even under the condition of limited rainfall, the variety SW Dansadau 2007 gave the best LAI value (3.22) with the N fertilizer application of 120 kg ha^{-1}.

Negative relationships between the levels of nitrogen fertilizer leaf area ratio (LAR) were observed in the two years of the study (Table 03), with LAR decreasing with increased N fertilizer rate with higher values in 2015 than in 2014. Similar results have been reported for maize (Abayomi and Fagbenja, 2005). In line with an earlier report of Bueno (1979) who worked on grain sorghum, Abayomi and Fagbenja (2005) also established a negative correlation between the LAR and other physiological growth parameters which responded positively to increasing rate of N fertilizer applications.

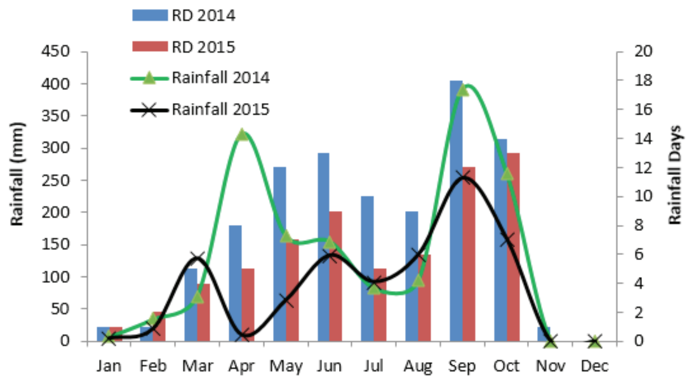

Figure 01: Average monthly rainfall distribution and monthly rainfall days (RD) of the experimental site in 2014 and 2015 cropping seasons

Table 02: Effects of variety and N fertilizer on the plant heights (cm) of sweet sorghum at 4 to 10 weeks after sowing (WAS) in the 2014 and 2015 cropping seasons

Treatments	4		6		8		10	
	2014	2015	2014	2015	2014	2015	2014	2015
Variety (V)								
NTJ-2	29.28ᵃ	38.89	55.31ᶜ	55.33ᵃ	106.87ᵇᶜ	103.55ᵇ	158.21ᵇ	146.83ᵇ
64 DTN	26.16ᵇ	33.25	56.82ᶜ	48.05ᵇ	103.71ᶜ	97.56ᵇ	148.66ᵇ	139.51ᵇ
SW Makarfi 2006	24.90ᵇ	37.42	64.61ᵇ	62.17ᵃ	116.76ᵇ	129.35ᵃ	172.28ᵃ	168.54ᵃ
SW Dansadau 2007	29.21ᵃ	38.30	70.97ᵃ	59.97ᵃ	134.71ᵃ	127.01ᵃ	181.17ᵃ	177.17ᵃ
SED	0.93	3.21	1.78	2.94	5.31	4.37	5.74	3.75
$LSD_{(0.05)}$	2.29	ns	4.36	7.20	13.00	10.68	14.05	9.18
Fertilizer (F) (kg N ha^{-1})								
0	26.16	34.10	49.43ᵇ	48.68ᶜ	94.89ᵇ	84.98ᶜ	125.19ᶜ	127.04ᵇ
40	26.53	38.17	64.98ᵃ	60.53ᵃ	126.44ᵃ	116.62ᵇ	173.30ᵃᵇ	161.26ᵃ
80	29.31	36.60	67.81ᵃ	53.21ᵇᶜ	119.92ᵃ	119.75ᵃᵇ	173.89ᵃᵇ	165.83ᵃ
120	28.49	36.08	66.16ᵃ	58.91ᵃᵇ	123.35ᵃ	122.47ᵃᵇ	185.81ᵃ	167.75ᵃ
160	26.45	39.86	61.25ᵃ	60.56ᵃ	112.97ᵃ	128.02ᵃ	167.20ᵇ	168.19ᵃ
SED	1.84	2.21	3.78	2.97	7.10	4.71	8.97	5.31
$LSD_{(0.05)}$	ns	ns	7.69	6.05	14.46	9.59	18.26	10.81
Interaction								
V × F	ns	ns	ns	ns	*	*	ns	ns

Means followed by the same letters are not significantly different from each other at 5% probability level. $LSD_{0.05}$ = Least Significant Difference at 5% probability level. SED = Standard Error of Difference. ns = not significant. * - denotes significant means at 5% probability level.

Since the NAR is dependent on the dry weight and leaf area, any variations in these two parameters will ultimately have an effect on the NAR. Consequently in 2014, the varieties SW Makarfi 2006 and SW Dansadau 2007 had greater NAR values which could be attributed to their higher dry matter and leaf area values. The trend of NAR responses to N fertilizer rate was similar to what was obtained for the CGR. The positive response of NAR to N fertilizer rate can be attributed to the effect of nitrogen on leaf area expansion and photosynthesis. The application of N fertilizer significantly affected the CGR in sweet sorghum in this study. CGR increased with increasing N fertilizer up to 120 kg N ha^{-1}.

Table 03: Effects of variety and N fertilizer on the leaf area index (LAI), leaf area ratio (LAR, cm^2 g^{-1}), net assimilation rate (NAR, $g\ m^{-2}\ day^{-1}$), relative growth rate (RGR, $g\ g^{-1}\ day^{-1}$) and crop growth rate (CGR, $g\ m^{-2}\ day^{-1}$) of sweet sorghum during the 2014 and 2015 cropping seasons

Treatment	LAI		LAR		NAR		RGR		CGR	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Variety (V)										
NTJ-2	2.40	2.31^{b}	142.2	169.4	12.70^{b}	7.26	0.11	0.09	26.11^{bc}	14.24
64 DTN	2.28	2.51^{a}	152.4	168.6	12.60^{b}	7.45	0.11	0.09	24.82^{c}	15.69
SW Makarfi 2006	1.98	1.96^{c}	152.4	151.2	15.61^{a}	7.69	0.11	0.08	27.21^{b}	13.88
SW Dansadau 2007	2.32	2.21^{b}	164.9	150.6	14.89^{a}	8.05	0.12	0.08	29.96^{a}	16.26
SED	0.14	0.06	8.05	7.54	0.85	0.514	0.003	0.006	0.80	0.818
$LSD_{(0.05)}$	ns	0.16	Ns	ns	2.09	ns	ns	ns	1.96	ns
Fertilizer (F) (kg N ha^{-1})										
0	1.69^{c}	1.53^{c}	181.7^{a}	179.8^{a}	12.56^{b}	6.36^{d}	0.11	0.083	19.07^{d}	8.36^{c}
40	2.48^{a}	2.28^{b}	156.1^{b}	160.3^{b}	13.70^{ab}	7.43^{bc}	0.11	0.082	28.80^{b}	14.84^{b}
80	2.44^{a}	2.11^{b}	139.8^{cd}	163.3^{b}	14.99^{a}	6.81^{cd}	0.11	0.080	30.74^{ab}	12.72^{b}
120	2.46^{a}	2.61^{a}	133.3^{d}	143.9^{c}	15.02^{a}	9.02^{a}	0.11	0.090	31.52^{a}	19.79^{a}
160	2.15^{b}	2.71^{a}	154.0^{bc}	152.4^{bc}	13.48^{b}	8.43^{ab}	0.11	0.088	25.02^{c}	19.37^{a}
SED	0.13	0.13	7.34	6.15	0.70	0.514	2.52	4.516	0.98	1.15
$LSD_{(0.05)}$	0.27	0.26	14.95	12.52	1.43	1.047	ns	ns	1.99	2.34
Interaction										
V × F	ns	**	Ns	ns	ns	ns	ns	ns	**	**

Means followed by the same letters are not significantly different from each other at 5% probability level. $LSD_{0.05}$ = Least Significant Difference at 5% probability level. SED = Standard Error of Difference. ** - denotes significant at 1% probability level. ns = not significant

The effect of the reduction in rainfall in 2015 could also be seen in the trend of CGR response to N fertilizer in that year with no significant difference between the CGR values produced with the application of 120 and 160 kg N ha^{-1}. The CGR values recorded in the present study were within the range earlier reported by Sher *et al*., (2011) for forage sorghum (24.1 – 33.6 g m^{-2} day^{-1}).

Stalk Yield Response to Nitrogen Fertilizer Rates

The results of the fresh stalk yield (FSY) in both years of the study showed significant variation among the four varieties. In 2014, the variety SW Makarfi 2006 had the highest FSY, although the value was not significantly different from that of SW Dansadau 2007 which had the highest FSY value in the succeeding year (Table 04). Nitrogen fertilizer rates other than the control resulted in statistically similar FSY values in 2014, while in 2015, increase in nitrogen fertilizer from 0 to 80 kg ha^{-1} resulted in significant increase in the FSY, and further increase to 120 kg ha^{-1} and beyond had no significant effect. Increase in stalk yield with increase in N fertilizer rate has been attributed to its effect on the leaf area and LAI leading to increased photosynthesis and subsequently higher stalk yield (Kumar *et al*., 2012). The interactive effect of variety × N fertilizer on the FSY observed in the year 2015 is an indication that the varieties responded differently to fertilizer application especially under water limiting condition. SW Dansadau 2007 had the highest FSY value (20.32 t ha^{-1}) with the application of 120 kg N ha^{-1}. The average stalk length (ASL) was also observed to vary among the varieties with the tallest variety, SW

Dansadau 2007, having the longest stalks in both years (Table 04). Nitrogen fertilizer application was observed to significantly affect the stalk characteristics such as stalk length and stalk girth in 2015. Although no significant variations were observed on the effects of the N fertilizer rates on the average stalk girth (ASG) in 2014, it was observed that the application of N fertilizer increased the girth to certain extent. Almodares *et al*., (2008) and Almodares *et al*., (2013) have reported significant effects of N fertilizer on the stalk length and girth (or diameter) of sweet sorghum, which they attributed to the effect of nitrogen on plant growth through cell division and enlargement.

Brix, Juice and Ethanol Yield Responses to Nitrogen Fertilizer Rates

In 2014, the variety SW Dansadau 2007 had the least brix value (8.7) while in 2015 when water was limiting the variety produced the highest value of brix (15.5%),and significantly higher juice yield (Table 05). This might be an indication that the variety performs better under water limiting conditions. The low brix value of the variety SW Dansadau 2007 in 2014 affected the ethanol yield. Nitrogen fertilizer rates did not have any significant effect on the brix values in 2014. This is consistent with the findings of Balole (2001), Galani *et al*., (1991), Almodares *et al*., (2008) and more recently, Uchino *et al*., (2013), who have reported that N fertilizer application did not have any effect on the brix value of sweet sorghum.The result is however, in contrast with the reports of Kovacs and Gyuricza (2012) which showed that N fertilizer application affected the brix value, as was the case in the second year of this study. Significant effect of N fertilizer rates on the ethanol yield (EY) was observed in both years of the study with the variation more prominent in 2015, with the highest significant ethanol yield obtained at 80 kg N ha^{-1}, beyond which there was no significant increase.

Table 04: Effects of variety and N fertilizer on the fresh stalk yield (FSY, t ha^{-1}), average stalk length (ASL, cm) and average stalk girth (ASG, cm) of sweet sorghum during the 2014 and 2015 cropping seasons

Treatment	FSY		ASL		ASG	
	2014	2015	2014	2015	2014	2015
Variety (V)						
NTJ-2	21.49^{c}	20.09^{c}	130.8^{c}	132.3^{c}	1.57	1.52^{b}
64 DTN	22.50^{bc}	25.32^{a}	127.7^{c}	125.1^{c}	1.60	1.68^{a}
SW Makarfi 2006	28.03^{a}	22.59^{b}	165.5^{b}	148.1^{b}	1.59	1.51^{b}
SW Dansadau 2007	25.74^{ab}	27.75^{a}	186.6^{a}	166.3^{a}	1.60	1.48^{b}
SED	1.41	1.02	3.80	3.05	0.12	2.24
$LSD_{(0.05)}$	3.45	2.49	9.30	7.46	ns	5.49
Fertilizer (F) (kg N ha^{-1})						
0	15.08^{b}	15.43^{c}	145.9	130.9^{c}	1.53	1.31^{d}
40	26.02^{a}	23.69^{b}	155.8	151.0^{a}	1.56	1.56^{bc}
80	27.01^{a}	27.41^{a}	153.9	143.8^{ab}	1.62	1.50^{c}
120	26.90^{a}	27.22^{a}	152.3	139.8^{b}	1.61	1.75^{a}
160	27.19^{a}	25.95^{a}	155.3	149.1^{a}	1.64	1.62^{b}
SED	1.67	0.79	6.17	3.85	0.07	4.24
$LSD_{(0.05)}$	3.41	1.61	ns	7.83	ns	8.63
Interaction						
V × F	ns	**	ns	ns	ns	ns

Means followed by the same letters are not significantly different from each other at 5% probability level. $LSD_{0.05}$ = Least Significant Difference at 5% probability level. SED = Standard Error of Difference. ** - denotes significant at 1% probability level. ns = not significant

Table 05: Effects of variety and N fertilizer on the brix (%), juice yield (JY, t ha^{-1}) and ethanol yield (EY, L ha^{-1}) of sweet sorghum during the 2014 and 2015 cropping seasons

Treatment	Brix		JY		EY	
	2014	2015	2014	2015	2014	2015
Variety (V)						
NTJ-2	15.6^{a}	12.0^{d}	13.71^{c}	12.92^{d}	958.7^{a}	689.6^{c}
64 DTN	16.4^{a}	13.0^{c}	14.75^{bc}	16.06^{b}	1057.4^{a}	940.3^{b}
SW Makarfi 2006	11.3^{b}	13.5^{b}	18.83^{a}	14.54^{c}	929.6^{a}	872.4^{b}
SW Dansadau 2007	8.7^{c}	15.5^{a}	16.44^{ab}	17.49^{a}	610.1^{b}	1197.5^{a}
SED	0.61	0.15	1.01	0.56	69.72	41.15
$LSD_{(0.05)}$	1.49	0.36	2.47	1.37	162.68	100.69
Fertilizer (F) (kg N ha^{-1})						
0	12.8	10.9^{d}	8.77^{b}	9.76^{d}	488.0^{b}	465.3^{d}
40	12.9	12.5^{c}	17.01^{a}	14.90^{c}	941.2^{a}	829.1^{c}
80	12.5	14.6^{b}	17.98^{a}	17.24^{ab}	964.5^{a}	1114.4^{a}
120	13.5	15.1^{a}	17.90^{a}	17.72^{a}	1028.4^{a}	1183.9^{a}
160	13.3	14.4^{b}	18.01^{a}	16.64^{b}	1034.2^{a}	1032.0^{b}
SED	0.88	0.24	1.38	0.50	110.39	35.84
$LSD_{(0.05)}$	ns	0.49	2.81	1.01	226.59	73.00
Interaction						
V × F	ns	**	ns	**	ns	**

Means followed by the same letters are not significantly different from each other at 5% probability level. $LSD_{0.05}$ = Least Significant Difference at 5% probability level. SED = Standard Error of Difference. * and ** - denote significant at 5% and 1% probability levels respectively. ns = not significant

The higher sugar yield can be attributed to a significant increase in the juice volume and constant or increasing brix values as nitrogen input increased. These results are well supported by the results presented by Almodares *et al.,* (2008) and Reddy *et al.,* (2007), who pointed out that the juice volume of sweet sorghum increased with nitrogen application. The variety SW Dansadau 2007 produced the highest ethanol yield with the fertilizer rate of 120 kg N ha^{-1} in 2015, when significant variety × N fertilizer interaction was observed.

Second degree polynomial (quadratic) regression satisfactorily expressed the relationship between the N fertilizer rate and the EY as observed in this study, with an R^2 value of 0.99 (Fig. 02). The result also shows that increase in N fertilizer resulted in increase in EY up to 120 kg ha^{-1}, beyond which a drop in EY was observed. On the fitted curve, the highest ethanol yield value (1,119.50 L ha^{-1}) was produced by the N fertilizer rate of 115 kg ha^{-1}. It should however, be noted that no significant difference was observed in the effect of N fertilizer rates between 80 and 120 kg ha^{-1} on the ethanol yield of sweet sorghum. This is different from the observation of Amall *et al.,* (2011) who pointed out that there is significant economic benefit in increasing N fertilizer rate to and beyond 112 kg ha^{-1}.

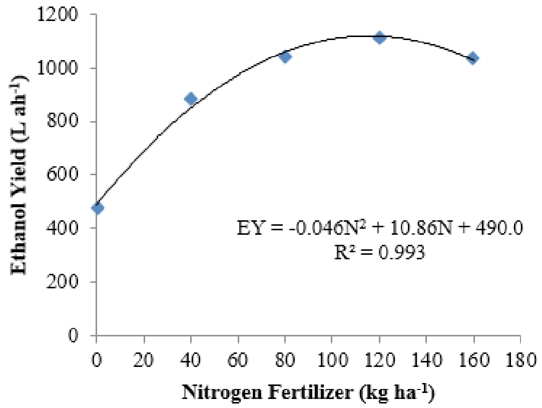

Figure 02: Observed and fitted relationships between nitrogen fertilizer (N) and ethanol yield (EY) of sweet sorghum

CONCLUSION

The study has shown that there were variations among the four varieties of sweet sorghum investigated. The application of N fertilizer has also been demonstrated to have positive effects on the growth characteristics and ethanol yield of the crop. The responses of the crop to N fertilizer have however been found to be affected by other environmental factors such as soil moisture. The variety SW Dansadau 2007 has been shown to have greater growth and yield characteristics when compared with the other varieties. The performance of the variety was much better in 2015 when there was a drop in the rainfall of the study area, suggesting that the variety will perform better than others under water stress, a situation that is a regular occurrence in the study location. Nitrogen fertilizer rate up to 80 kg ha^{-1} resulted in the increase of most parameters and ethanol yield, beyond which either there was no significant difference or a drop in the values of these parameters. Further research on the crop's response to other macronutrients, and an investigation into the appropriate plant population for optimum ethanol yield in the study area is recommended.

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