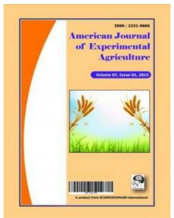

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Impact of NPK Treatments on Sweet Sorghum (*Sorghum bicolor* (L)) Yields for Biofuel Feedstock in Piedmont Region of North Carolina

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Authors' contributions

This work was carried out in collaboration between all authors. Author AD participated in this study as a graduate student. He collected samples and analyzed data and prepared manuscript. Author RR was involved in sample processing, data analysis and manuscript preparation, review and submission. Authors MR, RG, VR, GG and LW served as Master's thesis advisors for author AD and reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Alternative sources for biofuel production such as juice extracted from sweet sorghum are in high demand and proper nutrient management practices need to be established for growing sweet sorghum in order to maximize profits. Sweet sorghum (*Sorghum bicolor* (L.) *Moench)* is a promising alternative energy crop. A field experiment was conducted on a North Carolina Piedmont soil to evaluate the production of sweet sorghum as a feedstock for bio-ethanol. Two varieties of sweet sorghum (Dale and M81-E) and four fertilizer treatments (T1: 0, T2: 168-56-168, T3: 84-28-84-soysoap, T4: 168-56-168-Soysoap, of N-P_2O_5-K_2O kg ha^{-1}). The experiment was conducted at the North Carolina A&T research farm in 2011. Dale and M-81-E varieties of sweet sorghum

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produced significantly higher yields of tops fresh weight and stalk fresh weight from all fertilizer treatments (T2, T3 & T4) than the control (T1). Quantity of juice extracted from stalks was significantly higher for all fertilized treatments compared with the control, but was not affected by variety. No significant difference was observed in total sugar levels in all fertilized treatments. Across all measured variables, T3 gave significantly higher yields than the control but not from T2 or T4. T3 treatment involves half the amount of fertilizer than T2 & T4 and a surfactant effectively cutting fertilizer input expenses by 50%.

Keywords: Biofuel; ethanol; North Carolina; Piedmont; sweet sorghum.

1. INTRODUCTION

Growing interest in using ethanol produced from various plant species as a renewable substitute for fossil fuels in the USA and worldwide has prompted to conduct this study. The production of bio-ethanol in the USA increased from 175 million gallons in 1980 to 13.5 billion gallons [1]. The U.S. Energy Independence and Security Act of 2007 (EISA) set a standard renewable fuel consumption of 36 billion gallons, of which 21 billion gallons should be from cellulosic ethanol and other advanced bio-fuels by 2022 [2]. Currently in North Carolina, 5.6 billion gallons of petroleum-based liquid fuels are consumed each year [3]. The North Carolina Strategic Plan for Biofuels Leadership set a goal that by 2017, 10% of North Carolina's liquid fuels (about 600 million gallons) per year will be produced in the state from locally grown biomass [3].

Corn (*Zea mays* L.) grain is currently the major source of bio-ethanol production in the United States [4]. However, corn is an energy and nutrient intensive crop and is a major food and feed source in the U.S. Increasing production of ethanol from corn grain would likely lead to an increase in food prices as corn would be diverted from the food chain to producing ethanol [4]. Thus, energy crops other than corn must be considered to achieve the projected ethanol production of the U.S. An ideal dedicated energy crop for commercial ethanol production should provide positive production economics, should have high energy efficiency, and should fit into the ecosystem with minimal negative environmental consequences.

Sweet sorghum (*Sorghum bicolor* (L.)) is a promising crop for production of bio-ethanol and has relatively low input requirements, efficient water usage, wide adaptability to environmental conditions, and high yields of readily convertible sugars [5]. Sweet sorghum is a C4 annual grass with greater N use efficiency and biomass yield potential than corn [6]. Sweet sorghum is a subspecies of the sorghum family and has similar characteristics as other sorghum species, but with high sugar concentration in stalks. Sweet sorghum has a rapid growth rate as well as high sugar and biomass accumulation, drought and water logging tolerance, and wide adaptability [7-9]. The water requirement for sweet sorghum production is 8000 $m^3\ ha^{-1}$, which is half that of sugarbeet (*Beta vulgaris*) and one quarter that of sugarcane (*Saccharum officinarum L.)*, due to the extensive root system and relatively short growing season for sweet sorghum [10].

Sweet sorghum and sugarcane are advantageous energy crops compared with other crops since they have readily available sugars in their stalks, and produce bagasse (solid residue) after sugars are extracted [11]. Bagasse can be used as an animal feed [12] and as a soil amendment after composting [13]. Bagasse is also a viable biomass for cellulosic ethanol production and residual solids can be burned for heating [14]. Previous studies indicate that sweet sorghum has potential to produce 8000 L ha^{-1} ethanol, which is twice that of corn grain ethanol yield potential and 30% greater than sugarcane productivity (e.g., 6000 L ha^{-1} in Brazil) [5,15,16]. Sweet sorghum grain yield ranges from 1.5 to 7.5 t ha^{-1}, brix indexes range from 13 to 24%, juice sugar content varies from 7.2 to 15.5%, stalk fresh yield ranges from 24 to 120 t ha^{-1}, and biomass yield ranges from 36 to 140 t ha^{-1} [17]. Sweet sorghum has potential to produce greater biomass yield than a sugarcane crop in tropics [18]. The bagasse produced from sweet sorghum has higher biological value than sugarcane as animal feed [19], and greater micronutrient and mineral value [20]. Feedstock from sweet sorghum is an inexpensive source for integrated bio-refineries to produce high value products from the hexose feed stream and ethanol from cellulose-derived sugars [5,21]. The bagasse from sweet sorghum is also a potential raw material for the production of paper pulp [22] and energy source for combustion, gasification, and pyrolysis processes [23]. Sweet sorghum is a good source of ethyl *tetra*-butyl ether (ETBE) which can be added to gasoline to increase the octane index and reduce amount of non-combusted compounds [24]. However, ethanol production from sweet sorghum has limitations, such as storage of harvested product and that conversion of sugars into ethanol must initiate soon after harvest. Delay in conversion will lead to souring of juices (sugars convert to organic acids) and lower ethanol productivity [25].

The growth and production characteristics of sweet sorghum are favorable for commercial ethanol production. There are approximately 4000 sweet sorghum cultivars distributed throughout the world, providing a diverse genetic pool for development of specific and high yielding varieties for each region. Dale variety was developed in Mississippi mainly for syrup production [26] but gained popularity as biofuel feedstock. The Piedmont region of North Carolina has ideal climatic conditions for sweet sorghum cultivation, yet there is limited literature available regarding the nutrient requirements, potential biomass, and juice yields. Therefore, this study was conducted to assess nutrient management and determine yield potential for sweet sorghum in the North Carolina Piedmont region.

2. MATERIALS AND METHODS

2.1 Experimental Site

Sweet sorghum field experiment was conducted at the North Carolina A&T State University research farm, Guilford County, North Carolina (36.06, -79.73, 241.4 m elevation). The soil at the experimental location is a Mecklenburg sandy clay loam (fine, mixed, active, thermic Ultic Hapludalfs) [27], with 2 to 6 percent slopes, and moderately eroded.

2.2 Treatments

The experiment included two varieties of sweet sorghum, Dale and M81-E (produced at Mississippi Foundation Seed Stocks), and four fertilizer treatments. Fertilizer subplot treatments included: T1: 0 fertilizer (control), T2: 168-56-168 (N-P_2O_5-K_2O kg ha^{-1}), T3: 84-28-84 plus Soysoap (Biobased USA, Mocksville, NC) (0.6 L ha^{-1}), and T4: 168-56-168 plus Soy soap (0.6 L ha^{-1}). These rates were based on soil test. The fertilizer sources and application timing included 14-14-14 (N-P_2O_5-K_2O), triple super phosphate (0-45-0) and muriate of potash (0-0-60) at planting and NH_4NO_3 (34-0-0) applied as sidedress at 35 days after emergence. The side-dress application was incorporated in a band 5cm deep and 10cm from the row. Soysoap is a surfactant, which when applied as foliar spray is reported to enhance plant nutrient uptake and growth, vigor, disease resistance and yield. Soysoap was applied as a foliar surfactant once every two weeks (15 ml in 3.5 L of water) until the soft dough grain stage.

2.3 Sweet Sorghum Field Preparation

Sweet sorghum plots were plowed to 30 cm, disked, and planted with crimson clover and rye as cover crops in the Fall of 2010. In late spring of 2011, the cover crops were disked back into soil at flowering stage. Prior to sweet sorghum planting soil at the site was plowed to 30 cm and then disked. Plots were then laid out and treatments were randomized. One-third of N and all of the P_2O_5 and K_2O were applied at planting and the remaining two-thirds of the N was side-dressed.

Sweet sorghum was planted on May 23, 2011. The spacing was 25 cm within the row and between rows was 75 cm. Plots were irrigated using overhead sprinkler system supplementing rainfall. The plant population was manually thinned 3 weeks after planting to maintain 25 cm spacing within the row. Established sweet sorghum plant population was 132,500 stands/ha. Significant weed pressure was observed in the first 30 days after planting. In addition to manual weeding, post emergence (atrazine) herbicide was applied three weeks after planting at label rates. Shoot borer (*Chilo patillus*) infestation was observed in the plots at 40 DAP and anthracnose stalk rot disease was noted during the growing season. Carbaryl (1 Quart per acre in 100 Gallons water) insecticide (Sevin, Bayer Crop Science, Research Triangle Park, NC) and a fungicide Dithane M45 (Dow AgroScicences, Indianapolis, IN) at 1.5 lb/ac rate were applied at label rates to control the pest infestations.

Dale variety was harvested in first week of September followed by variety M-81-E in the second week of September. At harvest, tops fresh weight (including stalk, leaves and panicles), fresh stalk weight (without leaves and panicles), and the total juice extracted were recorded. A subsample of stalk and leaves were collected at each harvest, then oven dried at 70℃ to a constant dry weight to estimate moisture content.

2.4 Climate Data

Climate data were recorded using an automatic weather station (ECONET station) located approximately 50 m from the experimental plots. The recorded data were retrieved from NC CRONOS Database v.2.7.2 of the State Climate Office of North Carolina (http://www.nc-climate.ncsu.edu/). Daily weather data included maximum (Avg. TMAX) and minimum (Avg. TMIN) temperatures, relative humidity (Avg. R HUM), average wind speed (Avg. WIND), total solar radiation, photo-synthetically active radiation (PAR), precipitation (Total RAIN), and open pan evaporation (Total EVAP). Daily data were then averaged for individual months (Table 1). In 2011, the photosynthetically active radiation (PAR) was greater than in the previous year (2010) and may have had an effect on crop growth.

2.5 Experimental Design and Statistical Analysis

The experimental design was a 2×4 strip plot with 4 replications was used to improve homogeneity in the plots with 4 fertilizer treatments. Individual subplots measured 6 m×10 m. The variety treatment was randomized to main plots and fertilizer treatments were randomized to subplots. Sweet sorghum yield response to treatments was tested using analysis of variance by the PROC ANOVA model [28]. All statistical results were considered significant at 95% confidence level ($p \le 0.05$).

2.6 Sampling

In the sweet sorghum growing season, 6 random soil cores from the top 15 cm were collected and composited from each plot at planting and at harvest. The composite soil samples were air dried for 48 hours, ground to pass through a 2 mm stainless steel sieve, and analyzed for soil chemical and physical properties. Soil pH, cation exchange capacity (CEC), humic matter and bulk density were determined by the soil testing laboratory at the North Carolina Department of Agriculture and Consumer Services (http://www.ncagr.gov/agronomi/stmethod.htm). Soil at the experimental site had pH:6.2, CEC: 4.8 meq/100 cm^3, and humic matter content (w/v) (g/cm^3) 0.31%.

A specific set of parameter data was measured from a randomly selected 0.5 m^2 area of each plot, in two week intervals after planting. These parameters included: number of plants, number of leaves per plant, plant height, fresh biomass weight (including roots, stalks, leaves and panicles), dry biomass weights, root fresh weights, root dry weights, and from 4th sampling onwards: Stalks fresh weight, stalks dry weights, leaves fresh weight and leaves dry weights. Dry weights were determined by collecting a subsample from each fresh sample and drying at 70℃ until dry weights were constant. Sweet sorghum was harvested manually at dough (grain filling) stage and juice was extracted using a sugarcane juice extractor (Model # SLR 3, Global Restaurant Supplies, Inc., North Miami, FL). One liter of juice was extracted from sweet

Table 1. Monthly weather data during sweet sorghum growing season

Month	Avg. TMAX	Avg. TMIN	Avg. R HUM	Avg. WIND	Total RAIN	Total EVAP	Total solar radiation (TSR)	Photosynthetically active radiation (PAR)
	(°F)	(°F)	(%)	(mph)	(in)	(in)	(W/m^{2})	(mol/m^2)
May-10	79.0	60.1	70.9	3.93	6.69	11.57	14025	613.4
Jun-10	88.4	68.9	69.7	2.94	2.96	14.55	16184	703.0
Jul-10	89.3	69.4	68.2	2.70	7.53	14.77	16294	717.6
Aug-10	87.8	69.2	74.4	2.58	3.9	12.30	13928	607.6
Sep-10	84.7	61.7	65.0	3.16	6.53	9.97	12061	534.4
Oct-10	73.2	48.6	65.3	3.35	2.69	7.23	10516	474.8
May-11	77.8	57.3	72.6	2.40	3.59	5.92	7607	1240.0
Jun-11	88.2	66.0	64.5	2.72	8.85	7.39	8699	1467.7
Jul-11	90.4	70.4	70.6	2.26	5.01	7.26	8232	1396.4
Aug-11	88.7	68.0	66.0	2.96	2.43	6.34	7369	1254.1
Sep-11	80.4	61.6	74.2	2.74	10.11	4.92	6110	737.3
Oct-11	73.2	48.6	65.3	3.35	2.69	7.23	10516	474.8
Nov-11	60.9	37.6	64.4	3.19	0.93	1.85	2325	326.6
Dec-11	41.3	25.5	59.8	3.77	2.42	0.95	1116	263.1

sorghum stalks and the weight was recorded to calculate the overall juice yield per treatment. The extracted juice was stored in Polyurethane bottles from Fisher Scientific Company for further processing. Brix readings were recorded right at the time of juice extraction. The juice samples were oven dried at 105°C for 48 hours to determine water content. Sweet sorghum juice was fermented by a modified method of Sluiter et al. [29] and analyzed for total sugars (sucrose, fructose, and glucose) content using high performance liquid chromatography (Waters, HPLC Detector 410 Differential Refraction Index, Milford MA).

3. RESULTS AND DISCUSSION

The mean sweet sorghum tops fresh weights across all the fertilizer treatments were significantly different, but were not affected by varieties (Table 1). All plots receiving fertilizer treatments had yields significantly greater than control (26.8 ton ha^{-1}). There was no significant interaction between variety and fertilizer treatment (Table 2). The non-significant difference between the top fresh yields of the two varieties can be attributed to the suitability of the weather and soil conditions for both varieties in the piedmont area.

Table 2. Fresh biomass yield (ton/ha) of sweet sorghum (including stalks, leaves, and panicles) for two varieties and across multiple fertilizer treatments

Fertilizer treatment (kg ha^{-1})	Stalk fresh weight (ton/ha)		
N-P_2O_5-K_2O	**Dale**	**M-81-E**	**Mean**
Control	21.5	32.1	26.8 [b]
168-56-168	50.8	52.1	51.5 [a]
84-28-84-soysoap	50.3	64.5	57.4 [a]
168-56-168-soysoap	36.0	50.0	43.0 [a]
Mean	39.6	49.7	

Means with the same case letter within a year are not significantly different at α=0.05.

Stalk fresh weights (without leaves, panicles) showed a similar treatment response to that found for tops fresh weight in both varieties. Fertilizer treatments did not affect stalks fresh weight, nor was there a significant interaction between variety and fertilizer treatment. Tops fresh weight and stalks fresh weight were not affected by variety, but were affected by fertilizer across both varieties. All plots receiving fertilizer had greater yields than the zero fertilizer control (Table 3).

Table 3. Sweet sorghum final fresh stalk yield at harvest

Fertilizer treatment (kg/ha)	Stalks fresh weight (ton/ha)		
N-P_2O_5-K_2O	**Dale**	**M-81-E**	**Mean**
Control	15.5	20.6	18.1 [b]
168-56-168	38.1	38.1	38.1 [a]
84-28-84-soysoap	37.5	46.3	41.9 [a]
168-56-168-soysoap	26.1	36.3	31.2 [a]
Mean	29.3	35.3	

Means with the same case letter are not significantly different at α=0.05.

Final juice yield extracted from harvested stalks was not affected by varieties, but was affected by fertilizer treatment. All plots treated with fertilizer resulted in significantly greater juice yield (11,504 L ha^{-1}) compared with the zero fertilizer control yield (4,304 L ha^{-1}) (Table 4). This result is consistent with the results observed for tops and stalk yields. There was no significant interaction between variety and fertilizer for total juice yield.

Table 4. Sweet sorghum final juice yield at harvest

Fertilizer treatment (kg/ha)	Total juice (liters/ha)		
N-P_2O_5-K_2O	**Dale**	**M-81-E**	**Mean**
Control	4277	4331	4304 [b]
168-56-168	12887	10273	11580 [a]
84-28-84-soysoap	13411	13950	13681 [a]
168-56-168-soysoap	8348	10154	9251 [a]
Mean	9731	9677	

Mean values with same letter are not significantly different at α = 0.05.

Total sugar (including sucrose, fructose, and glucose) concentration in juice extracted from harvested stalk was similar for each variety tested. Total sugar concentration in juice was not affected by variety or fertilizer treatment (Table 5). The interaction effect of variety and fertilizer treatments was not significant.

BRIX readings recorded were significantly greater for variety Dale (14%) compared to variety M-81-E (13%), but were not affected by fertilizer rate. There was no significant interaction between variety and fertilizer treatments for BRIX, which is consistent with the pattern observed for sugar concentration (Table 6). Plant stress resulting from the lack of fertilizer in control plots resulted in higher sugar concentration. The higher sugar concentration in control is due to lower biomass production. Furthermore, the lower sugar concentration in the fertilizer treatments could be attributed to higher biomass production, which resulted in the dilution of the sugars.

Table 5. Sweet sorghum total sugar level of sucrose, fructose, and glucose in juice at harvest

Fertilizer treatment (kg/ha)	Per cent sugar level		
$N-P_2O_5-K_2O$	**Dale**	**M-81-E**	**Mean**
Control	10.4	11.74	10.89
168-56-168	11.81	11.31	11.56
84-28-84-soysoap	10.07	10.77	10.42
168-56-168-soysoap	13.10	10.19	11.64
Mean	11.25	11.00	

Mean values with same letter are not significantly different at $\alpha_{=0.05}$.

Table 6. BRIX index in sweet sorghum juice samples at harvest

Fertilizer treatment (kg/ha)	BRIX reading of juice at harvest (%)		
$N-P_2O_5-K_2O$	**Dale**	**M-81-E**	**Mean**
Control	11.6	12.4	12.0
168-56-168	14.9	14.4	14.7
84-28-84-soysoap	14.9	12.8	13.9
168-56-168-soysoap	14.5	12.5	13.5
Mean	14.0 [a]	13.0 [b]	

Mean values with same letter are not significantly different at $\alpha = 0.05$.

Total sugar and BRIX should have similar response patterns, since BRIX is a measure of solid sugars in juice samples. However, the values of sugar content and BRIX are different based on the fact that total sugar level is a measure of sucrose, fructose, and glucose. Sugar yield from the juice extracted was calculated based on the sugar concentration of juice (Table 7). There was no significant effect of variety or fertilizer treatments on sugar yield. However, differences in sugar yield among fertilizer treatments were significant at $p = 0.05$, when all fertilized treatments produced higher sugar yield (1,290 L ha^{-1}) than the zero fertilizer control (501 L ha^{-1}). Sweet sorghum biomass production study has shown mixed results for different fertilizer treatments. Our results were similar to results reported from previous research studies (7). The tops fresh weights, stalk fresh weights, extracted juice, and total sugar levels were similar to the sweet sorghum yields reported in previous research (17). Sweet sorghum variety M-81-E tops fresh yield/biomass ranged from 38.4 to 49.7 ton/ha, whereas variety Dale yield was 27.6 to 39.6 ton/ha.

Table 7. Sweet sorghum sugar yield

Fertilizer treatment (kg/ha)	Sugar yield in (liters/ha)		
$N-P_2O_5-K_2O$	**Dale**	**M-81-E**	**Mean**
Control	448	553	501
168-56-168	1567	1146	1356
84-28-84-soysoap	1424	1506	1465
168-56-168-soysoap	1090	1026	1058
Mean	1132	1058	

Greater PAR was recorded during the growing season (Table 1), which likely influenced the greater crop yields recorded. Overall, the fertilizer rates tested across the board didn't yield significantly different results, but the treatment T3 which has only 50% of the fertilizer dose than T2&T4 with a surfactant yielded same or higher biomass, juice, sugar, and brix compared to T2 & T4. Higher rates of NPK nutrient inputs did not produce linear increase in the sweet sorghum biomass yield.

4. CONCLUSIONS

Sweet sorghum experimental results with different fertilizer treatments produced higher tops fresh weight and stalk fresh weight than the zero fertilizer control. The juice extracted from stalk was greater for all fertilized treatments compared with the zero fertilizer control, but was not affected by variety. Total sugar levels and BRIX responded to fertilizer treatments similarly, in that all fertilized treatments had greater sugar percentage than the control, but no significant difference was observed. Overall yields in all measured variables, T3 (84-28-84 Kg ha^{-1} plus soysoap) resulted in greater yields than the control but was statistically equal to that of other higher fertilizer rates. Based on the data, treatment T3 gave significantly higher yields than T1 and T2 treatments. So a fertilizer rate of 84-28-84 (N-P-K) Kg ha^{-1} plus soysoap can be recommended for sweet sorghum producers in piedmont area of North Carolina for both Dale and M-81-E varieties.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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