Effect of nitrogen fertilization timing on juice and bagasse quality of sweet sorghum for biofuel production

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Abstract
Sweet sorghum biomass yields vary with hybrid, however, there is limited research done on how varying levels of nitrogen interacts with hybrids in affecting biomass produced and quality of extracted juice. The objective is to determine the forage and ethanol yield and quality under different Nitrogen management conditions. A three year experiment was initiated at Dupy farm, Gene Autry, OK in 2008. The treatments are two varieties (Topper and M81E) and seven nitrogen rates arranged in a RCBD with three replications. Sweet sorghum was harvested at soft dough stage and evaluated for total biomass yield, juice yield, forage quality at the time of harvest and quality of bagasse. Forage yields ranged from 60.5 to 94.9 tonne /ha and 75.5 to 98.2 tonne /ha in 2008 and 2009, respectively. Juice yields ranged from 7481 to 12626 litres /ha and 8587 to 13368 litres/ha in 2008 and 2009, respectively. There were no significant quality differences among nitrogen rates. The bagasse has 69, 3.9, 39.2, 66.3, 58.4 and 69, 4.7, 37.5 62.2, 59.6 % moisture, % Crude protein, ADF, NDF and TDN in M81E and Topper respectively. There was a positive response to fertilizer rates in 2008 and no significant difference in 2009.

Key Words
NUE, forage quality, biofuel, ethanol, nitrogen use efficiency.

Introduction
Energy demand in the world is increasing ever year due to increased consumption. Currently, US imports more than 60 % of its oil needs, so alternative renewable energy sources are warranted. Demand for ethanol is increasing drastically due to its direct use as well as blending in automotive fuels, which is desirable for getting clean exhaust and also to significantly reduce United States' dependence on foreign oil. U.S. produced around 6.5 gigalitres of ethanol in 2007, mostly from corn. In U.S. currently, sweet sorghum *(Sorghum bicolor* L.), is produced mainly for cooking and as a livestock feed after its introduction from Africa. It has a high water use efficiency, rapid growth rate, early maturity and high total value. Sweet sorghum can be grown throughout temperate climate zones of the United States, including Oklahoma. Sweet sorghum is a drought-tolerant feed stock with the potential to produce more ethanol per acre than corn. Steduto *et al.* (1997) reported that water use efficiency of sweet sorghum at canopy level is higher than maize and grain sorghum. The crop only needs 30-38 cm of rain during the growing season to make a crop. Therefore, it is suitable for dry land production or limited irrigation. If the crop receives more moisture, it will respond positively to water. Freeman *et al.* (1973) has reported that sweet sorghum has given yield responses to N applications of 45 to112 kg N/ha.

The idea of using sweet sorghum for commercial ethanol production is not new. Currently about 10 million tons of grain from the tops of the plant's stalks are harvested in the U.S., the world's leading grower, but most of the sugar from the stalks goes to make syrup for human and animal consumption. Sweet sorghum stalks contain up to 75% juice, varying between 12 and 23% in sugar. Antonopoulou *et al.* (2008) reported that sweet sorghum contains 43.6 – 58.2% soluble sucrose, glucose and fructose in the stalk and 22.6 – 47.8% insoluble cellulose and hemicelluloses. There's enough juice in a hectare of sweet sorghum to make 3700 to 7400 litres of ethanol. Sorghum juice-derived ethanol is cheaper to produce than corn ethanol because it doesn't require the cooking and enzymes that corn requires for conversion of starch to sugar to fuel grade alcohol. Current estimates suggest that intensive plant breeding and cultivation research could, over time, increase the sugar content of sorghum juice to a level needed to produce 9348 litres of ethanol per hectare. The taller the plant and the thicker the stalk, the more juice the plant will produce. The crop is long-rooted and can extract residual nitrogen left by previous crops, or from nitrogen-fixing soybeans preceding in crop rotation. The reason sweet sorghum is not as popular as corn in terms of being a source of ethanol in the United States has been the need to ferment its simple sugars immediately and the high costs associated with a centralized processing plant that can be operated only seasonally. Some of the crop residue left after juice extraction (bagasse) can be dried and burned to fuel ethanol distillation. These residues can also be used for animal feed, paper, or fuel pellets. Ensiled bagasse has potential feed value for beef cattle. Depending on cellulosic biofuel refinery feasibility, bagasse can be baled and marketed to them.Vinasse, the liquid left over after distillation could be used as a fertilizer source. The crop needn't be grown on a farmer's best land, allowing the farmer to make use of poorer ground. The simplicity of ethanol production from sweet sorghum could lend itself to on-farm or small-cooperative efforts at fuel-making.

In Oklahoma, the potential processing scenario might look like this: Plant sweet sorghum around mid-April, and then stagger plantings for two to three months. This would provide a harvest window of August through November. Limited research has been reported regarding the amount of nitrogen fertilizer required to optimize the juice production.The yields vary with the hybrid that is used for production and also there is limited research done on how varying levels of nitrogen interact with the juice yield quality and quantity of different hybrids. In order to address these questions of ethanol productivity and utilization of bagasse as a fodder from sweet sorghum, Noble Foundation in collaboration with the Oklahoma State University established a sweet sorghum variety by nitrogen fertility trial. The objective of this research is to evaluate sweet sorghum cultivars to determine the yield and quality of sweet sorghum's forage under different nitrogen rates as well as improve pressing and fermentation methods for possible ethanol production.

Materials and Methods

This experiment was initiated at Dupy farm, Gene Autry, Oklahoma in 2008 on dale silt loam (Fine-silty, mixed, superactive, thermic Pachic Haplustolls). Soil samples from 0 to 15 and 15 to 30 cm depths. The treatments are seven different N rates (0-0, 0-56, 56-56, 56-112, 112-0, 112-56, 168-0 preplant - topdress rates in kg/ha with two cultivars (Topper and M81E). The topdress applications are done at 10 leaf stage. The experimental design is a randomized complete block design with three replications. The experimental unit size is 1.53 m X 6.1 m. Seed was drilled in 76.2 cm rows with a Hege 500 research plot drill. Weeds were controlled mechanically by rotary hoe and chemically with 2, 4-D in 2008. In 2009, seed treated with Concept III safener and Cruiser insecticide. Cinch ATZ was used as pre-emergence herbicide. Forage was harvested at soft dough stage by cutting the center two rows using a blade attached weed eater to measure total biomass, juice content, sugar quality, bagasse yield and quality. Fresh biomass weight was measured on farm using a scale attached to back of a pickup truck. Stalks were pressed to extract juice using a roller presser built at Oklahoma State University. Fresh biomass and bagasse subsamples of the harvested biomass were collected for dry matter determinations and forage nutrient analysis. Following drying at 60°C, samples were ground to pass a < 1 mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and prepared for nutrient analysis. Nutrient concentrations were estimated with near infrared spectroscopy (NIRS) analysis (Shenk and Westerhaus 1994) using equations developed by the NIRS Forage and Feed Testing Consortium and included dry matter, N, P, K, NDF, ADF, and in vitro dry matter digestibility (IVDMD), a laboratory bioassay that estimates the proportion of dry matter in forage digestible by a ruminant (Ball *et al.*. 2001).Analysis of variance was conducted using the mixed models procedure in SAS to determine main effects and interactions of nitrogen fertilizer rate and application time. Nitrogen rate and application time were considered fixed effects and replication random. Polynomial contrasts were computed to determine the quantitative relationship of N rate to biomass yield and nutrient concentration.

Results

Forage yields

Forage yields ranged from 60.5 to 94.9 tonne /ha and 75.5 to 98.2 tonne /ha in 2008 and 2009, respectively (Figure 1). There was a positive response to N in 2008, with increase in N the forage biomass production also increased in both cultivars M81E and Topper. Total forage biomass was not significantly affected by different N rates in 2009 in Topper. For M81E at lower N rates the total yields in 2008 were lower than yields in 2009 due to persisting weed competition from both pigweed and crabgrass and at higher N rates there was no significant difference among both years. In Topper year has significant effect only in the control plot and at any N fertility level year didn’t had a significant effect. In 2009 there was no significant difference in biomass yields which may be due 56 kg N/ha of residual soil N.

Juice yields

Juice yields ranged from 7481 to 12626 litres /ha and 8587 to 13368 litres/ha in 2008 and 2009, respectively (Figure 2). There was a positive response to N in 2008, with increase in N the juice yields also increased in

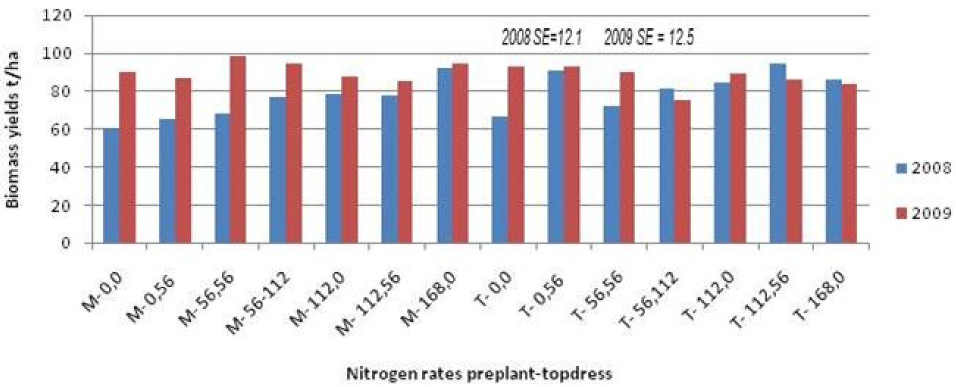

Figure 1. Forage biomass yields (fresh weight) in tonnes per hectare of M81-E (M) and Topper (T) under different rates and times of application of Nitrogen fertilizer at Dupy farm, Ardmore, OK.

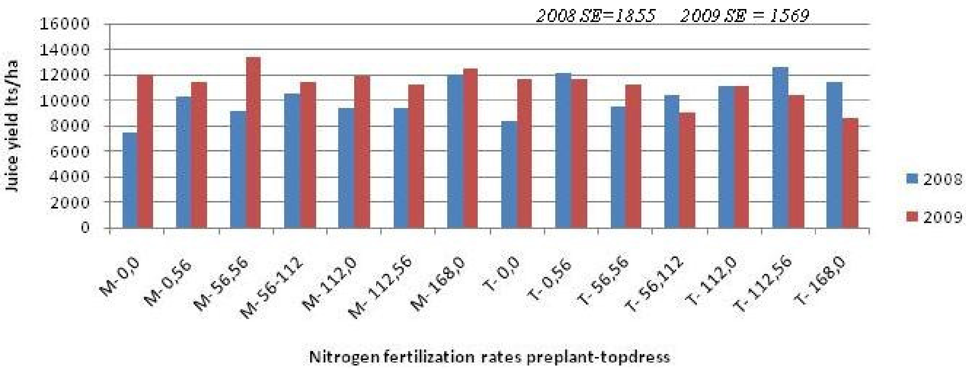

Figure 2. Juice yields in litres per hectare of M81-E (M) and Topper (T) under different rates and times of application of Nitrogen fertilizer at Dupy farm, Ardmore, OK.

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Moisture content and quality of forage and bagasse

The moisture content of forage ranged from 72 to 73% in both the varieties (Figure 4). The bagasse has 69, 3.9, 39.2, 66.3, 58.4 and 69, 4.7, 37.5 62.2, 59.6 % moisture, % Crude protein, ADF, NDF and TDN in M81E and Topper respectively. The higher moisture content in the bagasse indicates that there is room to improve press operation/pressure. The quality parameters of both the cultivars indicate that bagasse can be ensiled and used as feed for cattle

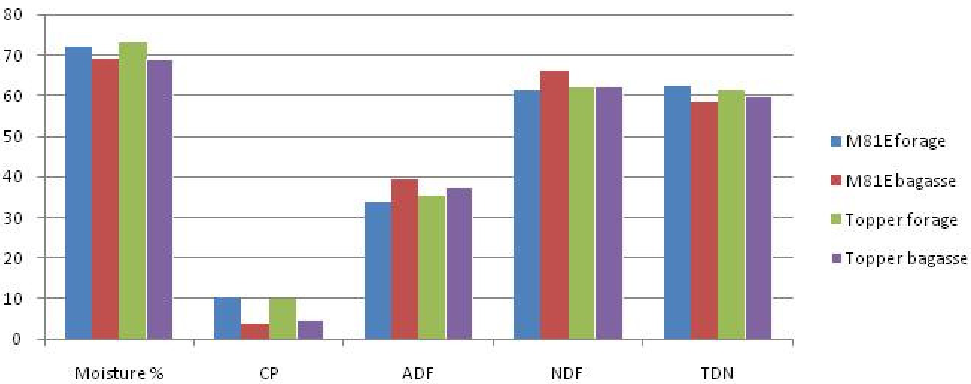

Figure 3. Forage and bagasse Moisture content and forage quality of M81-E and Topper at Dupy farm, Ardmore, OK.

Conclusions

This study evaluated the effects of nitrogen fertilization rates and timing on biomass yield and juice yields of two sweet sorghum cultivars M81E and Topper. Two years of study indicated that if there is enough residual nitrogen present in the soil the nitrogen fertilizer rates will not have a significant effect on forage yield as well as juice produced. If there is heavy weed pressure from pigweed and crabgrass M81E will tend to produce lower yields compared to Topper as evidenced in 2008 and under low weed pressure both the varieties produced almost the same amount of forage biomass and juice yields as evidenced in 2009 results. The bagasse left over after on farm extraction of juice has enough good quality that it can be ensiled and used as a feed for cattle. There is still some room to improve on farm extraction as evidenced by higher moisture content in bagasse that was left over after extraction of juice.

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