SWEET SORGHUM AS AN ALTERNATIVE CELLULOSIC BIOFUEL IN EASTERN KENTUCKY

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by

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SWEET SORGHUM AS AN ALTERNATIVE CELLULOSIC BIOFUEL IN EASTERN KENTUCKY

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Morehead State University, 2011

Director of Thesis: ______________________

Increased consumption of gasoline is going to require a new alternative ethanol source that will better meet the demand while offering additional economic and multifunctional benefits. Sweet Sorghum is a drought-tolerant, C_4 grass with a demonstrated high yield potential in Eastern Kentucky. A study was conducted in 2010 to determine the stem yield, syrup production, Brix content, whole plant yield, stalks per acre, and percent dry matter for whole and squeezed stalks of nine commercial sweet sorghum (Sorghum bicolor (L.) Moench) varieties. The biomass yield study indicated the cultivar Keller generally had the greatest yield.

These data suggest that Keller and Dale are highly productive in stem yield while Keller and M81-E were most productive in syrup production. There were strong tendencies for higher yielding varieties to have low Brix content. Whole plant yield (wet weight) ranged from 19,564 to 85,865 kg ha^{-1} for Umbrella and Keller, respectively. The number of stalks per hectare ranged from 59,200 to 299,230 stalks ha^{-1} for Umbrella and Keller, respectively. There is a 0.73 correlation value between the whole plant production and the number of stalks per hectare. These data suggest that Keller and M81-E varieties are consistently high producing varieties.

Accepted by: ______________________, Chair

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Acknowledgements

I would like to thank all of those who volunteered during the planting and harvesting of the sweet sorghum plot. Harvesting the sweet sorghum is a time consuming and monotonous task and could not have been accomplished without the hard work of others to contribute to this research. I would also like to thank my major professor, Dr. Mike Phillips, for his guidance and intellect in completing the research into this project.

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Literature Review

The continuous demand of ethanol consumption brings forth a need for new and alternative sources of ethanol production. Ethanol blend composes seven percent of the gasoline consumed in the United States (Anderson, 1995). Of this the United States derives more than ninety-five percent of their ethanol fuel from maize (*Zea mays*). Sugar cane (*Saccharum officinarum*) potentials of reducing greenhouse gas emissions by 90% in comparison to gasoline (van de Vorren & Zuurbier, 2008), as a cellulosic alternative, could directly correlate to the potential of sweet sorghum emissions. According to McKibben, global carbon emissions have raised to 8 billion metric tons a year, this is up from 3.7 billion in 1957 (McKibben, 1997). Sweet sorghum-based ethanol is sulfur-free and cleaner burning when mixed with gasoline (Holmseth, 2008). Currently, Kentucky is the leading state in sweet sorghum production, with estimates of over $12 million in syrup production in 2008 (Bitzer, 2009). Sweet sorghum is suitable for growing in less favorable conditions, compared to maize and sugar cane, producing high yields and less required inputs making it a more ideal ethanol alternative.

As a bioethanol production source, sweet sorghum has appeal in that it has a high green biomass yield of twenty to thirty dry tons per hectare (Dobbs et al. 1986). This is in part that sweet sorghum has a C_4 photosynthetic pathway able to yield higher dry matter production ($g/m^2/day$) through increased photosynthetic rate compared to crops such as sugar cane and sugar beets, that are also sugar producing (Akad et al. 2006).

The ratio of energy input used to produce a crop compared to the energy of the biomass product is an important characteristic when evaluating biomass crops. According to Joel Bourne, the input of the amount of fossil-fuel used to create an alternative fuel source needs to be less than the amount of energy that is produced (Bourne, 2007). The input to output ratio of different fuel sources as seen in Bourne (2007) are 1:1.3 for corn ethanol (corn), 1:2.5 for biodiesel (from plant oils), and 1:8 for cane ethanol (sugarcane) (Bourne, 2007). Sweet sorghum as a fuel alternative would be classified as a cane ethanol source having the lowest ratio of inputs to outputs making it ideal.

Efficient production demands a need to evaluate nitrogen requirements and application. This is attributed to rising prices of fertilizer costs, produced through the use of natural gas, and the diesel consumed by the machinery during production (Bourne, 2007). Compared to sugarcane, sweet sorghum requirements are decreased when evaluating fertilizer and water inputs. According to Akade et al. (2006) seasonal sugar cane fertilizer requirements (N:P:K) and water requirements (mm) are 250:115:115 and 2000-2200, respectively. Sweet sorghum fertilizer and water requirements are 100:50:50 and 400-450, respectively. The University of Kentucky's recommendation of fertilizer nitrogen (N) rates for corn is 125-170 lbs N/Acre, when planted after another grain crop such as soybeans (Lee, 2006).

The crop growing season must be evaluated for the time restraint that is required prior to the final product being produced. Sweet sorghum out-produces sugarcane because it matures within 100 to 120 days whereas the first crop of sugarcane takes one year to mature. In comparison, the majority of corn matures in 130 to 150 days (Neild & Newman, 1990) and some hybrid varieties maturing in 113 to 117 days (Lee, 2006). Weather conditions, particularly pertaining to the moisture and freezing possibilities of the soil, are going to influence the planting date which correlates to the maturity length of the crop. Sweet sorghum's optimum planting time is between May 1st and May 20th in Kentucky (Bitzer, 2002). Lee (2006) recommends that a mid to late April planting date be selected in Kentucky for growing corn. Crop producers ideally would like to plant their crop as soon as possible but if they do so before the recommended time they run the risk of a decreased yield due to freezing or flooding of the seed.

Crops utilized for both food and fuel have prices that are now determined by their value as a feedstock for biofuel rather than their value as human food or livestock feed (Council for Agricultural Science and Technology, 2006). According to Cassman and Liska (2007), increased food crop prices are driven by the precipitous increase in petroleum price. Sweet sorghum demonstrates to be more desirable in the conversion of total biomass yield to the amount of ethanol that can be produced. Through utilization of an alternative crop, sweet sorghum, will correspondingly address the concern of food verses fuel. Ismail Dweikat, associate professor at the University of Nebraska-Lincoln, explains that total biomass stover from corn is four to five tons per acre plus an additional 150 to 180 bushels of grain. Sweet sorghum typically yields 14 tons of biomass per acre, trumping corn when produced for cellulosic ethanol plants (Holmseth, 2008). Similarly, Wu et al. (2010) found in a study performed in 2007 that the dry mass yield for M81-E cultivar ranged from 20,373 kg ha^{-1} to 25,750 kg ha^{-1} averaging 24,366 kg ha^{-1} and 18,142 kg ha^{-1} to 32,024 kg ha^{-1} averaging 26,343 kg ha^{-1} for Riley and Doniphan counties in Kansas, respectively. There was no significant difference between average yields between the two counties. "The average corn yield in the U.S. is about 150 bushels per acre. The average ethanol yield per bushel is 2.8 gallons per bushel; that equates to an average production rate of 420 gallons per acre," states David Cukierman, president and chief executive officer of Ethano Peru LLC in Houston. The average sweet sorghum yield in the United States is based on two harvests per year averaging 1,424 gallons/acre production (Holmseth, 2008). Dweikat, however, compares sweet sorghum and corn ethanol yields being 800 and 250 gallons per acre, respectively (Hovey, 2006). The two studies differ in total ethanol produced per acre for each crop, nonetheless, supports that sweet sorghum is going to provide more products.

In addition to the biomass that is produced from sweet sorghum it also offers an additional benefit of producing syrup at the interior of the stalk. The stems of sweet sorghum differ from forage sorghum characteristically in being juicy not dry (d recessive to D) and sweet not nonsweet (x recessive to X) (Rooney, 2000). This syrup contains specific sugars that can be isolated and converted into ethanol. Compared to sugarcane, sweet sorghum has higher sugar content on a value basis, according to Dweikat (Holmseth, 2008). Relative percentages of fermentable sugars in sweet sorghum are approximately 70%, 20%, and 10% for sucrose, glucose, and fructose, respectively (Hoshi et al., 2007). Reducing sugars consist of glucose and fructose, while sucrose is a non-reducing sugar (Anderson, 1995). The presence of reducing sugars in sweet sorghum prevents crystallization and increased fermentation efficiency (Kachapur et al., 2005). It is important to have high sucrose levels, non-reducing, compared to reducing sugars on a weight basis because they produce approximately five percent more ethanol, according to Anderson (1995). Studies have found that sucrose levels increased as harvest approached and the inter-nodes elongated. Although the increase of sucrose occurred, the concentration differences differed as much as two times in certain varieties, such as Keller (Anderson, 1995).

Estimates as to the amount of sugar present in syrup extracted from sweet sorghum can be determined by using a hand refractometer. This method needs to be utilized in the field during harvesting to receive the most accurate reading. The number represented by percent Brix expresses the percent of soluble sugars present in the syrup. Extracted sweet sorghum juice varies in the amount of sugar present from 16-23% Brix (Kachapur et al., 2005). Potential ethanol yields of all fermentable sugars present in sweet sorghum could be 600-650 gallons per acre (Bryan et al., 1985). Studies show that there is high correlation (r=0.98) between the total reducing sugars present and the Brix of the syrup (Akade et al., 2006).

Instrumental technique, near infrared reflectance spectroscopy (NIRS), is used to determine specific sugars that are present. NIRS utilizes and records the specific amount of light that is reflected or transmitted, using wavelengths above visible light, through a forage sample (Ball et al, 2007). Prediction equations are developed from a series of calibration samples that are compared to wet chemical analysis to determine the desired constituents, which are not directly measured by the instrument. A study performed by Bolsen et al., (1996) describes a method used in developing a prediction equation by using selected means, standard errors, and coefficients for nutrient components of the sorghum. Prediction equations are an effective method in developing a more efficient method in analyzing sweet sorghum samples utilizing NIRS. Currently, there is not a comparison commercially available for which new samples can be analyzed against to give accurate readings of sweet sorghum syrup. The development of equations by NIRS is feasible for sweet sorghum, but additional work is needed to create a large database encompassing different varieties over consecutive years to validate the equation and NIRS results.

The potential of a crop to produce high levels of ethanol is going to be greatly influenced by the chemical composition of the plant at the time of harvest, according to the results found by Fales et al., (2010). Maturity stages of sweet sorghum have been identified using a numbering system ranging from zero to nine. Beginning at day zero, emergence (0), leading up to half-bloom (6), soft dough (7), hard dough (8), and finally physiological maturity (9) occurs approximately 95 days after emergence. The variety and the environmental conditions that sweet sorghum are exposed to are factors that are going to affect the time it is going to take to reach a particular stage of maturity (Vanderlip, 1993). Akade et al., (2006) report that crop harvesting should occur at physiological maturity to yield high grain levels and obtain optimum sugar content, higher than 15% Brix. If deheading prior to harvest is desired as the University of Kentucky suggests, this would occur approximately two and a half weeks prior to harvest, at the late milk stage (Bitzer, 2002). Wu et al., (2010) suggests harvesting the stalks by hand, removing the heads and leaves, and then pressing the stalks for syrup collection.

Correlation of collected data will contribute to the specific variety that is chosen for crop production to obtain the highest yields. Anderson (1995) reported that the number of days to full blossom (anthesis) provides indication of relative maturity and linked to other yield characteristics as follows:

Cultivar	Days to anthesis	Percent Moisture	Dry Matter	Total sugar	Potential ethanol
	Pounds/acre			gal/acre	
Sugar Drip	**93**	**76**	**14,107**	**6,607**	**449**
Theis	**101**	**74**	**14,911**	**6,607**	**449**
M81-E	**104**	**76**	**16,161**	**6,429**	**437**
Dale	**107**	**77**	**14,107**	**6,964**	**474**
Keller	**107**	**75**	**15,982**	**7,411**	**504**

The cultivars presented are in order of maturity. This indicates that the M81-E cultivar stands out from the others as being high yielding. The greatest dry matter yield in respects to late maturity was Keller. Keller produced 741 pounds of sugar per acre, equivalent to 500 gallons of ethanol, assuming 14.7 pounds of sugar equal one gallon of ethanol. In this study different site locations were utilized in planting and harvesting the sweet sorghum cultivars (Anderson, 1995). The differences among yield characteristics, Anderson (1995) suggests, could be due to site fertility, latitude, and climatic differences in years, however, the rank of cultivars remained the same.

Improvement of sweet sorghum varieties are being conducted to influence desirable characteristics including: biomass yield, syrup production, lodging resistance, seed production, and syrup quality. Bitzer et al., (2010) determined through studies conducted in 2004 and 2005 in Lexington, Kentucky that hybrid varieties of sweet sorghum, Dale and Sugar Drip, produced greater stalk yield through increased plant height and diameter. Selected sweet sorghum hybrids, A_3 N100 x Dale, were able to produce increased total syrup yields compared to conventional varieties (Bitzer et al., 2010). Hybrids such as KNMorris, a male-sterile hybrid developing no seed head, released by the University of Kentucky has the ability to yield 25% more juice, resulting in more syrup (Bitzer, 2002).

The correct hybrid and harvesting equipment to extract the sweet sorghum juice during harvesting still has to be developed before sweet sorghum can become more efficient as a cellulosic biofuel alternative, according to Ishmail Dweikat (Hovey, 2006).

Little previous research has investigated production capabilities for sweet sorghum in Eastern Kentucky. Therefore, the objectives of this research were to evaluate sweet sorghum cultivars in Eastern Kentucky. Emphasis was placed on biomass and juice yields, as well as the Brix values. Ethanol production processes will require a high amount of biomass with high fermentable carbohydrates for optimal ethanol output.

Ethanol from sweet sorghum would reduce the need for government support of grain prices, stabilize oil prices, and partially replace oil with a renewable source of energy. This study has helped to define the type of sweet sorghum that would produce maximum dry matter and sugar yield in Eastern Kentucky.

Materials and Methods

A study was conducted in 2010 at Morehead State University's Derrickson Agricultural Complex, DAC, (38.22° latitude; -83.48° longitude) on a Tilsit silt loam soil (Fine-silty, mixed, semiactive mesic, Typic, Fragiudalfs (USDA, 2010)). The plot area prior to planting was composed of tall fescue and white clover which was tilled and prepared for planting. Cultivars planted included: Dale, Sugar Drip, Della, TOP 76-6, Simon, M81-E, Keller, Umbrella and Theis.

A randomized complete block design was used for this study, utilizing a John Deere 7200 Max Emergence planter. Plots consisted of two rows (76.2 cm spacing), 7.62 meters long and replicated four times. Plant population was four seeds per 0.305 meters. Border rows were not utilized for the interpretation of agronomic data. Preplant fertilizer (19-19-19) was broadcast and incorporated to a depth of approximately 10 cm at 392 kg ha^{-1}.

The sweet sorghum was harvested on September 17, 2010. Different stages of maturity were represented due to the difference in maturity lengths of the varieties. Representative samples were collected by hand in 3.05 meter sections. Seed heads were removed, leaves stripped and weighed. The number of stalks per 3.05 meter sections were counted then squeezed once through a Blymyer Iron Works sugar press and ran through a filter composed of cheese cloth to remove undesirable particles. The syrup was then collected into a five gallon bucket. Syrup was weighed on a Denver Instrument MZ-11 portable scale (0.000 kg accuracy) and sub-samples were collected and frozen at -12°C for future analysis. Brix content was determined from the sorghum syrup utilizing a Fisher Scientific Hand Refractometer, Brix 0-18% with 0.1° Division and ±0.1° Accuracy.

Sub-samples were collected for squeezed and unsqueezed stalk comparisons. Three stalks were randomly chosen from each remaining plot and harvested by hand. The seed heads and leaves were removed leaving the bagasse. The stalk sub-samples were then placed into a paper bag, weighed, and wet weights were recorded. Three stalk samples were randomly chosen from each plot after being squeezed through the sugar press, placed into a paper bag, weighed, and wet weight recorded.

The stalk samples were dried in a forced air oven for one week at 60 degrees Centigrade and dry weights were recorded in order to determine dry matter yield and moisture content. The stalk samples were ground using a Wiley Mill with a 1 mm screen and stored for further analysis.

For each variety fifty seeds were chosen randomly and the diameter was recorded using the widest part of the seed. Seed size measurements were performed using a digital caliper and measured to the nearest 0.001 mm. The diameters were determined for subsequent evaluation of plant populations in the field study.

Data were analyzed by analysis of variance (ANOVA) using of SAS (Statistical Analysis System version 9.1, SAS Institute, Cary, NC) Generalized linear model (GLM) procedure. Sweet sorghum variety was included in the KIND statement and repetitive position (1-4) in the field included in the BLOCK statement. Calculations were performed for two treatments. Treatment A comprising unsqueezed stalks and treatment B comprising squeezed stalks. Least significance difference means were estimated and single degree of freedom comparisons made among LSDMEANS. Comparisons were declared significant at $P<0.05$. Correlations were produced with PROC CORR using SAS. LSD (0.05) = 0.095.

Results and Discussion

Plots were harvested on a single harvest date with sweet sorghum cultivars at the approximate growth stages: half bloom for TOP 76-6 and Keller, soft dough for M81-E, hard dough for Della and Dale, and physiological mature for Simon, Umbrella, Sugar Drip, and THEIS. Unsqueezed stalk dry matter percent (Table 1.1) ranged from 25.85 to 31.76 for M81-E and Simon, respectively. Whole plant unsqueezed stalk production ranged from 19,564 to 85,865 kg ha^{-1} for Umbrella and Keller, respectively. Total stem production, stripped stalks (Table 1.5), ranged from 15,514 to 67,082 kg ha^{-1} for Umbrella and Keller, respectively. Syrup production (Table 2.3) ranged from 774.2 to 2,797.9 kg ha^{-1} for Simon and Keller, respectively. Brix content ranged from 13.4 to 17.8 for M81-E and TOP 76-6, respectively. These data suggest that Keller and Dale are highly productive in stem yield while Keller and M81-E were most productive in syrup production. There were strong tendencies for higher yielding varieties to have low Brix content (Figure 1.1). The number of stalks per 0.305 meters ranged from 1.38 to 6.95 for Umbrella and Keller, respectively. The calculated total stalk count (Table 2.7) ranged from 59,200 to 299,230 stalks ha^{-1} for Umbrella and Keller, respectively. There is a 0.73 correlation value between the whole plant production and the number of stalks per hectare. These data suggest that Keller and M81-E varieties are consistently high producing varieties. Total dry biomass (Table 2.10) of cultivars ranged from 987 to 6,362 g ha^{-1}. Comparison of syrup yield to total dry biomass (Figure 1.2) suggest that cultivars producing higher dry biomass tended to be lower in syrup production. Plant density was inversely correlated to total dry biomass (Figure 1.3). This demonstrates that the higher stalk producing varieties do not yield the highest total biomass.

The LSD means for seed size measurements ranged from 2.676 to 3.308 mm for Umbrella and THEIS, respectively (Table 3.1).

Resulting information is only from one growing season, and interpretations and recommendations made from the data would be more conclusive with subsequent replications. However, confidence is found that a sufficient number of production samples were collected in 2010 to make a valid comparison of the cultivars performance.

Tables

Table 1.1 Results and analysis of variance of dry matter for unsqueezed stalks of different sweet sorghum cultivars.

Cultivar	Dry Matter[1] %	t Grouping
Simon	31.758	A
Sugar Drip	31.723	A
Dale	29.485	AB
TOP 76-6	28.945	AB
Della	28.873	AB
THEIS	27.928	B
Umbrella	27.338	B
Keller	26.123	B
M81-E	25.848	B

[1]LSD Means (0.05) = 3.7482

Table 1.2 Results and analysis of variance of whole plant for unsqueezed stalks of different sweet sorghum cultivars.

Cultivar	Whole Plant[1] *Kg*	t Grouping
Keller	19.958	A
M81-E	17.554	AB
Della	14.062	BC
TOP 76-6	13.926	C
THEIS	13.517	C
Dale	13.177	C
Sugar Drip	7.371	C
Simon	5.171	C
Umbrella	4.547	C

[1]Wet basis
LSD Means (0.05) = 3.5525

Table 1.3 Results and analysis of variance of whole plant per hectare for unsqueezed stalks of different sweet sorghum cultivars.

Cultivar	Whole Plant[1] *kg ha⁻¹*	t Grouping
Keller	85865	A
M81-E	75523	AB
Della	60496	BC
TOP 76-6	59911	C
THEIS	58154	C
Dale	56691	C
Sugar Drip	31712	D
Simon	22247	D
Umbrella	19564	D

[1]Wet Basis
LSD Means (0.05) = 15284

Table 1.4 Results and analysis of variance of stripped plant for unsqueezed stalks of different sweet sorghum cultivars.

Cultivar	Stripped Plant[1] *Kg*	t Grouping
Keller	15.593	A
M81-E	14.493	AB
Della	11.453	BC
Dale	11.295	BC
TOP 76-6	10.886	BC
THEIS	10.501	C
Sugar Drip	5.443	D
Simon	4.048	D
Umbrella	3.606	D

[1]LSD Means (0.05) = 3.6338

Table 1.5 Results and analysis of variance of stripped plant per hectare for unsqueezed stalks of different sweet sorghum cultivars.

Cultivar	Stripped Plant[1] *kg ha⁻¹*	t Grouping
Keller	67082	A
M81-E	62350	AB
Della	49275	BC
Dale	48592	BC
TOP 76-6	46836	BC
THEIS	45177	C
Sugar Drip	23418	D
Simon	17417	D
Umbrella	15514	D

[1]*LSD Means (0.05) = 15633*

Table 2.1 Results and analysis of variance of dry matter for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Dry Matter[1] %	t Grouping
Simon	35.275	A
Dale	34.945	AB
Sugar Drip	34.845	AB
THEIS	34.445	AB
TOP 76-6	34.418	AB
Della	34.32	AB
Umbrella	32.773	ABC
Keller	31.568	BC
M81-E	29.5	C

[1]*LSD Means (0.05) = 3.5063*

Table 2.2 Results and analysis of variance of syrup for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Syrup[1] *Kg/3.05 m*	t Grouping
Keller	1.301	A
M81-E	1.2415	AB
Della	0.9725	BC
TOP 76-6	0.9395	C
Dale	0.8527	C
THEIS	0.7841	CD
Sugar Drip	0.4986	DE
Umbrella	0.3674	E
Simon	0.36	E

[1]*LSD Means (0.05) = 0.2891*

Table 2.3 Results and analysis of variance of syrup per hectare for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Syrup[1] *kg ha^{-1}*	t Grouping
Keller	2797.9	A
M81-E	2669.9	AB
Della	2091.6	BC
TOP 76-6	2020.5	C
Dale	1833.8	C
THEIS	1686.3	CD
Sugar Drip	1072.3	DE
Umbrella	790.1	E
Simon	774.2	E

[1] *LSD Means (0.05) = 621.75*

Table 2.4 Results and analysis of variance of brix for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Brix[1] %	t Grouping
TOP 76-6	17.825	A
Dale	17.65	AB
Simon	17.625	AB
Della	16.5	BC
Umbrella	16.475	BC
THEIS	15.75	CD
Sugar Drip	15.45	CD
Keller	14.45	DE
M81-E	13:375	E

[1]*LSD Means (0.05) = 1.3151*

Table 2.5 Results and analysis of variance of stalk count per meter for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Stalk Count[1]	t Grouping
	# stalks/0.305 m	
Keller	6.95	A
Dale	5.40	AB
M81-E	4.70	B
THEIS	4.55	B
Della	4.33	B
TOP 76-6	3.55	BC
Sugar Drip	3.50	BC
Simon	2.10	C
Umbrella	1.38	C

[1]*LSD Means (0.05) = 2.1781*

Table 2.6 Results and analysis of variance of stalk count for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Stalk Count[1]	t Grouping
	# stalks/3.05 m	
Keller	69.50	A
Dale	54.00	AB
M81-E	47.00	B
THEIS	45.50	B
Della	43.25	B
TOP 76-6	35.50	BC
Sugar Drip	35.00	BC
Simon	21.00	C
Umbrella	13.75	C

[1]*LSD Means (0.05) = 21.781*

Table 2.7 Results and analysis of variance of plant population for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Stalk Count[1] *# stalks/ha^{-1}*	t Grouping
Keller	299,230	A
Dale	232,495	AB
M81-E	202,357	B
THEIS	195,899	B
Della	186.212	B
TOP 76-6	152,844	BC
Sugar Drip	150,692	BC
Simon	90,415	C
Umbrella	59,200	C

[1]LSD Means (0.05) = 21.781

Table 2.8 Results and analysis of variance of wet weight per 3.05 meters for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Wet Weight[1] *ww/3.05 m*	t Grouping
TOP 76-6	1113.3	A
M81-E	990.5	AB
Keller	912.8	ABC
Dale	833.8	ABC
Umbrella	786.8	ABC
THEIS	706.3	BC
Della	680.3	BC
Simon	629.5	BC
Sugar Drip	588.3	C

[1]LSD Means (0.05) = 383.18

Table 2.9 Results and analysis of variance of wet weight for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Wet Weight[1]	t Grouping
	g	
TOP 76-6	381.4	A
Dale	291.19	AB
M81-E	291.01	AB
Keller	284.69	AB
Umbrella	258.05	B
THEIS	242.15	B
Della	232.21	B
Simon	218.02	B
Sugar Drip	203.68	B

[1]LSD Means (0.05) = 120.53

Table 2.10 Results and analysis of variance of dry matter for squeezed stalks of different sweet sorghum cultivars.

Cultivar	Dry Matter[1] *g ha^{-1}*	t Grouping
Umbrella	6362	A
Simon	3743	B
TOP 76-6	2802	BC
Sugar Drip	2308	BC
THEIS	1857	BC
Della	1789	BC
M81-E	1626	BC
Dale	1369	BC
Keller	987	C

[1]LSD Means (0.05) = 2563

Table 3.1 Seed size results of different sweet sorghum cultivars.

Cultivar	Seed size[1] *mm*	t Grouping
THEIS	3.308	A
TOP 76-6	3.290	A
Sugar Drip	3.048	B
M81-E	2.948	C
Keller	2.786	D
Della	2.750	DE
Dale	2.726	DE
Simon	2.722	DE
Umbrella	2.676	E

[1]LSD Means (0.05) = 0.0946

Figures

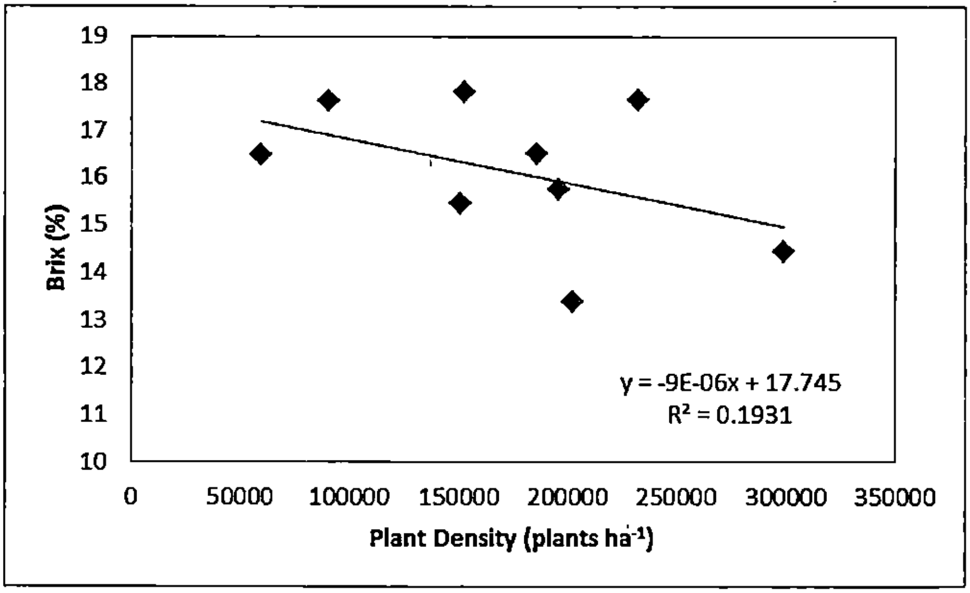

Figure 1.1 Relation of Brix to sweet sorghum plant density at DAC in 2010.

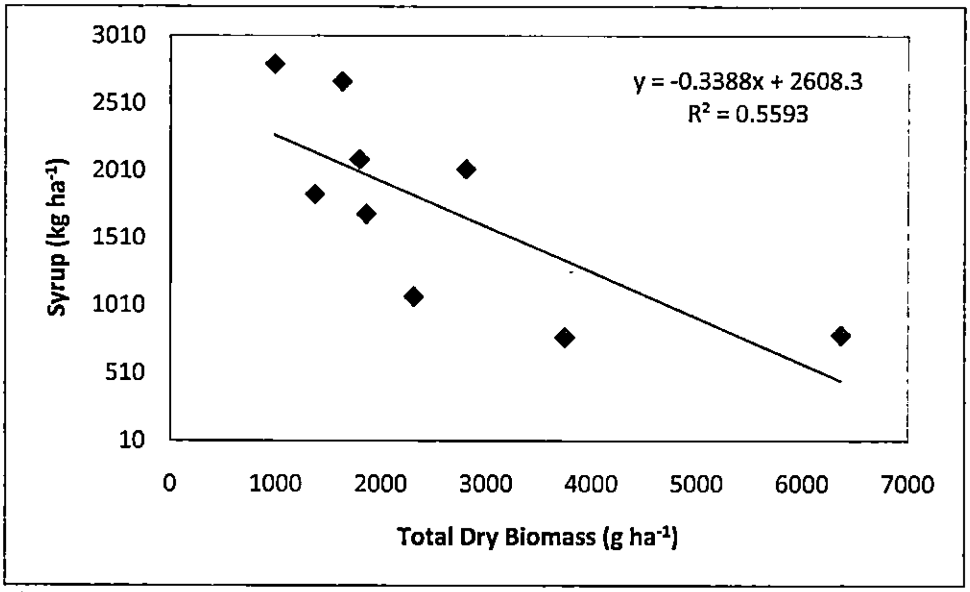

Figure 1.2 Relation of syrup yield to total dry biomass at DAC in 2010.

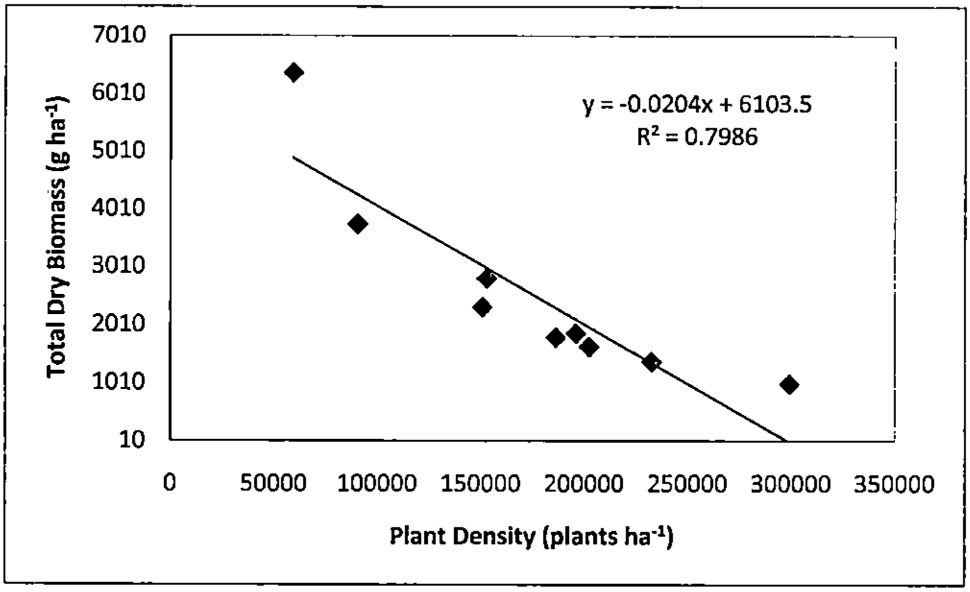

Figure 1.3 Relation of total dry biomass to plant density at DAC in 2010.

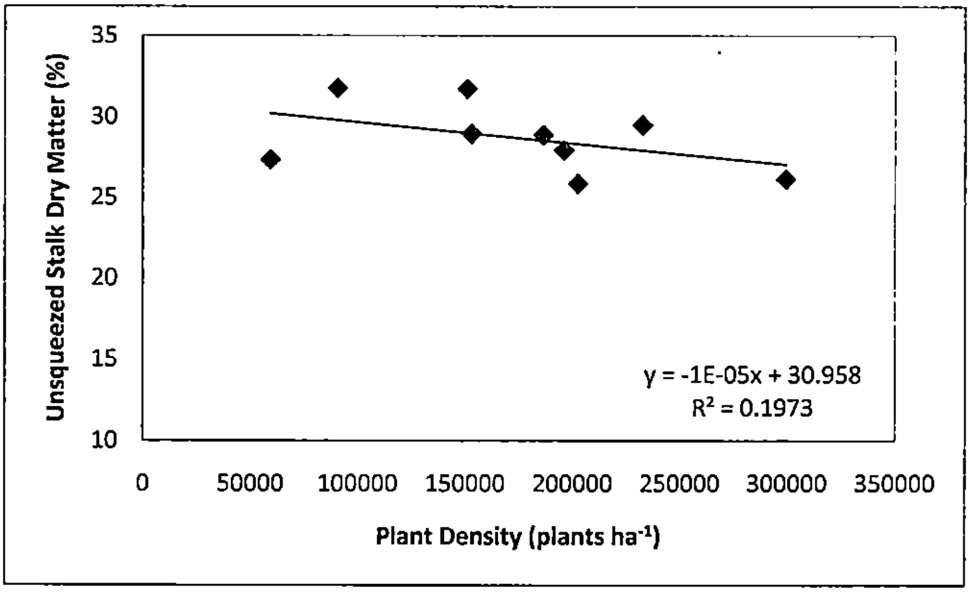

Figure 1.4 Relation of unsqueezed stalk dry matter to plant density at DAC in 2010.

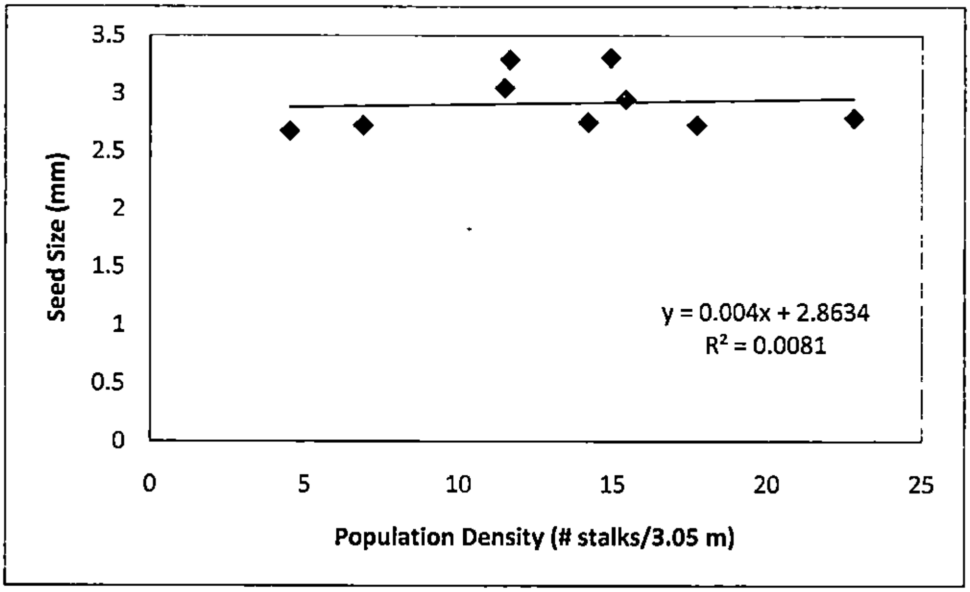

Figure 1.5 Relation of seed size to population density at DAC in 2010.

Summary and Conclusions

The results that have been examined during this study conclude that the highest yielding varieties, M81-E and Keller, are supported by similar findings in a study performed in Louisiana, with the highest yielding variety produced under numerous variables (nitrogen application, plot location, and planting density) was M81-E when compared to the other varieties observed: Topper, Theis, and Dale (Alison et al., 2009).

Plant densities determined ranging from 59,200 to 299,230 plants ha^{-1} in this study very closely parallel the plant density ranges reported by Dooley (2010) from 43,000 to 309,000 plants ha^{-1}. The broad range of plant populations demonstrates the importance of accurately choosing the variety that is going to be most advantageous.

Planting equipment was initially established for one seed size and variation in size was not taken into consideration prior to planting. Frederiksen (2000) described the seeding rate being effected by such elements as: "the size of the seed, the test weight of the seed, the shape of the seed, and the number of seeds per pound," (Frederiksen, 2000, p. 420). Future plantings need to incorporate alternate seed plates to better guarantee a proper seeding rate. A low correlation value, as displayed in Figure 1.5, of seed size in relation to population density was observed. Ideally, it would be expected that smaller seed diameter would attribute to higher population density but this was not the case. This could be attributed to factors such as nutrient competition and specific variety characteristics. The characteristics exhibited here include stalk diameter and height, plant maturity at time of harvest, and time to reach maturity. According to Doggett (1988) short stalk varieties yielded a higher biomass with a higher population. In comparison taller varieties had an increase in biomass production when they were planted at a lower population density of 20,000 to 30,000 plants/ha^{-1} compared to 65,000 plants/ha^{-1} (Doggett, 1988; p. 274). Additional studies would like to examine these characteristics and how they directly relate to variety yields. This can be accomplished through harvesting samples throughout the growing period at each stage of maturity, recording stalk diameter and height that equates to biomass yield, and obtaining syrup samples. Further analysis needs to be performed on the syrup production samples to determine specific sugars and composition of the syrup in comparison utilizing wet chemistry analyses.

"These approaches [soybeans, wind turbine, solar panel, and compact fluorescent bulbs] have one thing in common: They're more difficult than simply burning fossil fuel. They force us to realize that we've already had our magic fuel and that what comes next will be more expensive and more difficult" (McKibben, 2007, p. 35). In order to produce an efficient fuel source, there is going to be a continual demand in cutting costs, decreasing inputs and increasing outputs. This can be attained by utilizing sweet sorghum as an alternative cellulosic biofuel. Future work would be to develop a cultivar that is taller, larger diameter stalks containing exceptional quality syrup and deficient of a seed head.

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