The Canadian Society for Bioengineering
The Canadian society for engineering in agricultural, food, environmental, and biological systems.

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie
La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

CSBE | SCGAB

Paper No. CSBE11-307

The Potential of Forage Sorghum as a Direct Combustion Biofuel

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Written for presentation at the
CSBE/SCGAB 2011 Annual Conference
Inn at the Forks, Winnipeg, Manitoba
10-13 July 2011

ABSTRACT Increasing interest in renewable energy sources has been driving producers to investigate a wide range of crops for the biofuel industry. This study investigates the use of forage sorghum as a potential biofuel for direct combustion. A Canadian variety of forage sorghum (*Sorghum bicolor* subsp. *drummondii*) was planted in eastern Ontario to evaluate the effect of planting density and nitrogen fertilizer rates on the biomass production. The variety was CFSH 30 (single cut). The two planting densities were 12 and 18 kg/ha of seed, and fertilized with either 90 or 135 kg/ha of nitrogen. In total, there were 32 plots, allowing for 4 replications for each treatment. The crops were planted in the second week of June and harvested in the first week of August. Plant population was determined at the time of harvest. The harvested crop was weighed and samples dried to determine the moisture content. Dry biomass yields ranged from 1.6 to 4.8 t/ha, with an average of 3.1 t/ha. The average yields in plots seeded at 12 and 18 kg/ha were 2.9 and 3.4 t/ha, respectively. Fertilizer application rate had no effect on the crop yield, with the average yields for the 90 and 135 kg/ha of nitrogen application resulting in 3.1 and 3.2 t/ha, respectively.

Keywords: biofuel, direct combustion, sorghum, biomass.

Introduction Current concerns over the impact of greenhouse gas production from fossil fuels and increasing energy costs are driving the interest in renewable energy sources. Some of this attention has been turned towards biorenewable energy sources from agriculture, such as the production of biodiesel, bioethanol, electricity from methane digestion of animal manure, and combustion of biomass. Burning of biomass has opportunities in home heating, greenhouse and agricultural buildings heating, and replacing coal in large industrial-scale energy consumers and electricity producers. Biomass can be burned to produce steam, which in turn, is used to drive a turbo-generator for electricity production (McKendry, 2002a). Under normal practices, the amount of carbon emitted from the biomass can be similar to the amount of carbon that the plant consumed during its growth (McKendry, 2002a). Both annual and perennial crops have their place in energy production. Perennials have the advantage of reduced planting and tillage costs over the long-term. However, many of the popular perennials that are viewed as ideal for biomass production, such as switchgrass or miscanthus, can take several years to become fully established. Annuals have their place in the energy production as they can be established quickly to meet fluctuations in market demands. Some annuals, such as sorghum and millet, can be planted in late spring, and therefore can be used as an alternative crop if an early season crop fails to establish or if adverse climatic conditions significantly delay the planting season.

Sorghum has been used as forage for animals, as a source of grain, and used in the production of ethanol. Sorghum biomass yields depend on cultivar and nutrient application rates. Investigating literature values of dry matter production of sweet sorghum, Bennet and Anex (2009) determined that a reasonable average production for the upper Midwest of the US would be 17.3 t/ha. Hons et al. (1986) measured sorghum biomass yields at 12.8 t/ha for a high-energy sorghum cultivar with nitrogen application at 168 kg/ha, whereas the same cultivar without nitrogen application yielded 7.8 t/ha. For three different seeding rates, the average biomass yield were 5.3, 5.3, and 13.8 t/ha, for plant populations of 513,000, 733,000, and 1,165,000 plants per hectare, respectively (Tubeileh et al., 2009). Both single and multi-cut varieties exist for both these crops. Multi-cut varieties tend to have higher biomass production. The planting density of sorghum has been demonstrated to greatly affect the biomass yield of sorghum (Tubeileh et al., 2009).

The energy content of the crop, on a per area basis, is very important in the computation of the net energy use. Clearly, the use of fertilizers, pesticides, and field operations increase the amount of energy that goes into the production. In particular, the energy associated with the fertilizer can be a substantial amount of the total energy inputs. Furthermore, as nitrogen fertilizers are reliant on fossil fuels, their use is a concern with greenhouse gas emissions. For the purpose of direct burning, the mineral content of the biomass is an important factor. Sweet sorghum has been reported to have sulphur and ash contents that are 50 and 8 times lower, respectively, than that of lignite (Türe et al., 1997). The higher heating value of sweet sorghum has been measured to be 16.8 MJ/kg and ash and sulphur contents to be 2.18 and 0.09 %, respectively (Türe et al., 1997).

As part of a bioenergy production system, it is desirable to minimize input costs and input energy. If the final product is to be burned as an energy source, then the crop needs to be dried to an acceptable level prior to storage and densification (baling, pelletizing, etc.). In general, only biomass that has less than 50% moisture content is suitable for combustion (McKendry, 2002b). The lower the moisture content, the great amount of energy that is available if the latent heat of water vapour is not recaptured. Thus it is of interest to investigate the moisture content at time of harvest to gauge the amount of drying or dehydration that may be necessary. Many crops that are destined to be burnt as energy are harvested late in the season or are allowed to over-winter, resulting in a lower moisture content when baled. However, in these situations, there is also a loss in the total biomass.

The objective of this study is to determine the biomass yield of sorghum and to determine the effect of seeding rate and the fertilizer rate on the biomass production. The study is divided into two phases. The first phase is a preliminary large scale field operation to determine the potential biomass yield using typical seeding and fertilizer rates. The second phase studies the effect of seeding rate and the fertilizer rate on the crop establishment and biomass yield.

MATERIALS AND METHODS Sorghum was planted for two seasons. The first season, summer 2009, was a large scale planting following general production recommendations to give a baseline for the yield potential of forage sorghum as a biomass material for bioenergy. The second season, summer 2010, was a refined experiment based on the outcomes from the first year and was used to investigate the effects of seeding rate and fertilizer rates on the establishment and yield of forage sorghum.

Crop establishment - 2009 The plant material consisted of forage sorghum [Sorghum bicolor L. 'Canadian Forage Sorghum Hybrid 30' (CFSH 30)]. The experimental site is located in Kemptville, Ontario (45°00´ N, 75°37´ W) and was established on a 0.5 ha field with a loamy sand texture. The field was previously cropped to a perennial forage mixture (timothy, clovers and alfalfa), which was killed by two applications of Roundup on May 15th and June 7th. Composite soil samples were taken from the topsoil in early June before planting and sent to an accredited lab for analysis.

No seedbed preparation was performed before planting. Sorghum was planted on June 11th, using a no-till planter. The sorghum was seeded at 19 kg/ha. The seeding depth was 2.5 cm for sorghum with a row width of 19.05 cm. At planting, sorghum received 55 kg N/ha, 45 kg P/ha and 55 kg K/ha of fertilizer.

Crop establishment - 2010 The same variety was established in summer 2010 on a sandy loam soil in close proximity to the 2009 trial. Initial weed control was an application of Roundup on June 4th at a rate of 1.675 L/ha. On June 11th, the field was disked, soil samples were taken, an application of urea fertilizer was applied, and the seed was planted.

Soil samples were taken at 6 locations in the field. At each location, two depths were sampled, from 0 to 15 cm and 15 cm to 30 cm. A composite sample for each layer was made and sent to an accredited lab for analysis.

Two rates of urea were applied, at 196 and 293 kg/ha, resulting in nitrogen application of 90 and 135 kg/ha, respectively. Phosphorus and potassium fertilizers were not added as historical soil samples had indicated that this field had acceptable levels of both nutrients and should not be a hindrance for production. Two seeding densities were used; 12 and 18 kg/ha, with a row spacing was 19.05 cm.

Each plot measured 4.5 by 6.0 m, with the planting direction along the length of the plots. The plots were arranged contiguously in a 4 by 8 pattern. These dimensions include a 0.75 m buffer along each side of the plot and 1.0 m at the end of the plots. All analysis of crop yield was determined based on the 3.0 by 4.0 m dimensions. All possible combinations of factors were tested with four replicates.

Biomass yield estimation To estimate the biomass production and moisture content for the 2009 season, eight samples were taken manually just prior to the harvest on August 4th. Samples were randomly collected from different parts of the field using a 70 x 70 cm quadrat. Plants were cut at 20 cm above soil surface and all stalks were collected. The samples were weighed and the stalks were counted to determine the plant population. The samples were dried in a forced air oven at 65°C for three days. The dry weight was measured and the moisture content computed.

For the summer 2010 trials, the mass of all the biomass in a 3 x 4 m section of each plot was harvested and weighed on a tarp suspended from two digital scales. From each plot, 2 whole sorghum samples were collected and dried in an oven at 105°C until there were no more changes in plant matter mass.

Determination of energy content of biomass The higher heating value (*HHV*), in MJ/kg, of the biomass was calculated based on typical ash contents, A_0, of sorghum using the following equation (Sheng and Azvedo, 2005):

$$HHV = 19.914 - 0.2324 A_0 \quad (1)$$

The ash content used in the calculation was 4.4%, based on the findings of CSHF-30 in a similar experiment (Tubeileh et al, 2009). These values were used, along with the biomass production per unit area, to calculate the total energy production per unit area. These results do not take into account the amount of moisture in the crop, which decreases the available energy for direct combustion, especially if there is no mechanism to capture the latent heat associated phase change of biomass moisture into water vapour.

Soil analysis The results of the soil analysis are presented in Table 1 for the 2009 and 2010 growing season. For summer 2009, soil samples were taken at a 0-15 cm depth. In 2010, soil samples were taken at two depths, from 0-15 and 15-30 cm, and nitrate contents were measured.

Table 1. Soil analysis.

Parameter	Units	Year		
		2009	2010	
			0-15 cm	15-30 cm
N-NO3 (Nitrate)	ppm	-	11	14
pH		7	7.1	7.0
P (NaHCO3 Extractable)	ppm	36	22	24
K (NH4 Acetate Extractable)	ppm	109	97	107
Mg (NH4 Acetate Extractable)	ppm	342	283	323
Mn (Index)	ind.	16	13	13
Zn (Index)	ind.	23	41	50
Organic Matter (@350C)	%	3.4	5.3	5.1
Na (NH4 Acetate Extractable)	ppm	24	28	36
Ca (NH4 Acetate Extractable)	ppm	1630	2050	2140
CEC K	meq/100g	0.3	0.2	0.3
CEC Mg	meq/100g	2.8	2.3	2.7
CEC Ca	meq/100g	8.2	10.3	10.7
CEC Na	meq/100g	0.1	0.1	0.2
CEC Total	meq/100g	11	13	14

RESULTS AND DISCUSSIONS

Plant population The plant population per hectare was estimated to be 452,000 for summer 2009 based on a seeding rate of 19 kg/ha. At the November harvest, the plant population was estimated to be 709,000. This difference is due to the tillering of sorghum, where multiple stalks grow from the original plant material after the initial cut. For the summer 2010 trials, there were two seeding rates. The average plant populations per hectare for the seeding rates of 12 and 18 kg/ha were 227,000 and 296,000 plants, respectively. Based on the statistical analysis, these were significantly different, as one would expect. Although increasing the seeding rate from 12 to 18 kg/ha resulted in a 50% increase in the amount of seed, the plant population per hectare only increased by 30.4%.

The fertilizer rate, alone, had no significant effect on the plant population. However, an interaction between the seeding rate and the fertilizer rate was detected. The plant population at the lower fertilizer rate was not significantly different at the two different seeding rates. At the low seeding rate, the plant population was significantly higher with the lower fertilizer rate. Conversely, at the higher seeding rate, the plant population was significantly higher with the higher fertilizer rate.

These plant populations, however, were different between the two years due to the seeding rates. The seeds per kg of seed were measured to be 67,000. Thus, in summer 2009, the seeding density was 1,273,000 seeds/ha. The establishment for this year was 35.5%. For summer 2010, the seed rate was 804,000 and 1,206,000 seeds/ha, for the 12 and 18 kg/ha seeding rates, respectively. However, establishment for these trials were only 28.2 and 24.5%, for the low and high seeding rates, respectively. It is hypothesized that this poor establishment was due to planting in a sandy soil in combination with insufficient precipitation during the establishment period.

Table 2. Sorghum population and yield – summer 2009.

Dependent Variable	Units	Results	
		August	November
Population	plants/ha	452,000^{a}	709,000^{b}
Sorghum Biomass Yield	t/ha	4.41^{a}	4.68^{a}
Moisture Content	%	83.5^{a}	63.7^{b}
Average Plant Mass	g/plant (wet basis)	58.9^{a}	18.0^{b}
Dry Matter	g/plant	9.8^{a}	6.5^{a}

Means along rows with the same letter are not significantly different (*P*=0.05)

Table 3. Effect of seeding rate – summer 2010.

Dependent Variable	Units	Seeding Rate		
		Low	High	Average
Population	plants/ha	227,000^{a}	296,000^{b}	261,000
Biomass Yield	t/ha	2.88^{a}	3.40^{a}	3.14
Moisture Content	%	82.4^{a}	82.5^{a}	82.5
Average Plant Mass	g/plant (wet basis)	74.6^{a}	66.0^{a}	70.3
Dry Matter	g/plant	13.2^{a}	11.5^{a}	12.3

Means along rows with the same letter are not significantly different (*P*=0.05)

Table 4. Effect of fertilizer rate – summer 2010.

Dependent Variable	Units	Fertilizer Rate		
		Low	High	Average
Population	plants/ha	263,000[a]	260,000[a]	261,000
Biomass Yield	t/ha	3.15[a]	3.14[a]	3.14
Moisture Content	%	82.4[a]	82.6[a]	82.5
Average Plant Mass	g/plant (wet basis)	70.8[a]	69.8[a]	70.3
Dry Matter	g/plant	12.5[a]	12.2[a]	12.3

Means along rows with the same letter are not significantly different (*P*=0.05)

Table 5. Interaction between seeding rate and fertilizer rate – summer 2010.

Parameter	Units	Seeding Rate			
		Low		High	
		Fertilizer Rate		Fertilizer Rate	
		Low	High	Low	High
Population	plants/ha	260,000[a]	194,000[a]	259,000[a]	332,000[b]
Biomass Yield	t/ha	3.20 [a]	2.58 [a]	3.10[a]	3.70 [a]
Moisture Content	%	82.6 [a]	82.2 [a]	82.5 [a]	82.5 [a]
Average Plant Mass	g/plant (wet basis)	72.0 [a]	77.3 [a]	67.7 [a]	64.4 [a]
Dry Matter	g/plant	12.6 [a]	13.8 [a]	11.8 [a]	11.3 [a]

Means along rows with the same letter are not significantly different (*P*=0.05)

Biomass yield The biomass yield data for summer 2009 is shown in Table 2. The sorghum yield was 4.4 t/ha for the August harvest and 4.7 t/ha for the November harvest for a total yield of 9.1 t/ha. There was no significant difference in the yield for the two harvest dates, although there was a significant difference in the number of plants per hectare.

The average biomass yield for the summer 2010 season was 3.1 t/ha over all trials. The yields were 2.9 and 3.4 t/ha for the low and high seeding rates, respectively. Although the higher seeding rate had a 17.7% larger yield compared to the lower seeding rate, this was not statistically significant. The fertilizer rate had no effect on the biomass yield, with a yield of 3.1 and 3.2 t/ha for low and high fertilizer rates, respectively.

Moisture contents at harvest For the summer 2009 trials, there were significant differences in the moisture content at these two harvest dates, as there was a killing frost prior to the second harvest date. There is an advantage to the late harvest as it reduces the amount of drying that is required to obtain the desired moisture content for direct combustion. However, for climates such as that in eastern Ontario, there is little opportunity to field dry and harvest the crop in the late fall. The moisture contents of the crop in November of this study are far from the desired moisture content of 15% or below. There is the possibility of over-wintering the crop, much like what is performed for other bioenergy crops, such as switchgrass. However, this often results in significant losses in yield.

Average plant weight and dry matter content The average plant weight, on a wet basis, for the Summer 2009 trials were 58.9 and 18.0 g, for the August and November harvest dates, respectively. These were significantly different, mainly due to the fact that there was a significant difference in the moisture content at harvest. A more appropriate measure is the amount of dry matter per plant. These values were 9.8 and 6.5 g DM, for the August and November harvest dates, respectively. Although the August harvest date had on average a dry matter content 52% higher than the November harvest, the differences were not statistically significant, owing to a high degree of variance in the measured quantities.

The average plant weight (wet basis) for the summer 2010 trial had an overall average of 70.3 g. The slight differences based on seeding rate, 74.6 and 66.0 g, for the low and high seeding rate, were not significantly different. Theoretically, the seeding rate could affect the average plant weight as a lower seeding rate would result in less competition for resources, resulting in a larger plant. In much the same manner, one may expect the dry matter per plant to also be higher at a lower seeding rate. The dry matter per plant was 13.2 and 11.5 g for the low and high seeding rates, respectively. These differences were not statistically significant. Interestingly, these values were higher than the summer 2009 trials, which had an increased plant population. Unfortunately, these values cannot be compared statistically.

No effect of the fertilizer rate on the average plant weight and the dry matter per plant was observed. The average plant weight was 70.8 and 69.8 g for the low and high fertilizer rates, respectively. Similarly, as the moisture contents were essential identical, the dry matter content per plant was 12.5 and 12.2 g for the low and high fertilizer rates, respectively.

Energy potential The energy potential of the crop on a per area basis has been calculated based on the yields from this study and the typical energy content of sorghum biomass. Based on an ash content of 4.4%, the HHV for sorghum is estimated to be 18.9 MJ/kg. For the 2009 experiment, the calculated energy content of the sorghum biomass per unit area is 83.1 GJ/ha for the August harvest and 88.8 GJ/kg for the November harvest, resulting in a total of 171.9 GJ/ha. For the summer 2010 harvest, the total energy content was 58.6 GJ/ha.

CONCLUSION Forage sorghum was grown over two seasons to determine the biomass yield potential as a bioenergy crop. The first season was a preliminary study on a large scale to determine the yield that might be expected from typical seeding and fertilizer rates. The second season was a more rigid experiment where the seeding rates and fertilizer rates were varied to determine the effects of these parameters on the biomass yield and potential energy production from sorghum.

For both seasons there were some establishment issues that limited the biomass production. The first season had two harvest dates with a total biomass production of 9.1 t/ha. The first and second harvests were not significantly different, however there was a significant difference in plant population between the two harvest dates due to the effect of tillering. The second harvest in the late fall had approximately 57% more stalks than the summer harvest.

The second season consisted of 16 plots with two seeding rates, two fertilizer rates, and four replicates. The seeding rate significantly affected the plant population; however it did not affect the biomass yield or the dry matter per plant. The average yield was 3.1 t/ha. The two different fertilizer rates had no effect on the population, biomass yield, or dry matter per plant. Further research with more fertilizer treatments is needed to determine optimal fertilizer levels.

Acknowledgements Funding for this study has been provided through the OMAFRA/University of Guelph Research Program. The authors are grateful to AERC Inc. for the supply of the sorghum seeds and agronomic expertise.

REFERENCES

Bennett, A.S. and R.P. Anex. 2009. Production, transportation and milling costs of sweet sorghum as a feedstock for centralized bioethanol production in the upper Midwest. Bioresource Technology, Vol. 100: 1595-1607.

Hons, F.M., R.F. Moresco, R.P. Wiedenfeld, and J.T. Cothren. 1986. Applied nitrogen and phosphorus effects on yield and nutrient uptake by high-energy sorghum produced for grain and biomass. Agronomy Journal, Vol. 78: 1069-1078.

McKendry, P. 2002a. Energy production from biomass (Part 1): overview of biomass. Bioresource Technology, Vol. 83: 37-46.

McKendry, P. 2002b. Energy production from biomass (Part 2): conversion technologies. Bioresource Technology, Vol. 83: 47-54.

Sheng, C. and J.L.T. Azevedo. 2005. Estimating the higher heating value of biomass fuels from basic analysis data. *Biomass and Bioenergy*, Vol. 28: 499-507.

Tubeileh, A., T.J. Rennie, A. Kerr, and A. Mains. 2009. Commercial scale evaluation of maize and sorghum biomass production under marginal conditions in Eastern Ontario. In: Science for Sustanability: Soil, Agronomy, Atmosphere. Joint Annual Conference of the CSSS/CSA/CSAFM, Guelph, Canada.

Türe, S., D. Uzun, and I.E. Türe. 1997. The potential use of sweet sorghum as a non-polluting source of energy. Energy, Vol. 22(1): 17-19.