

# Feasibility of Ethanol Production from Sweet Sorghum in Kentucky

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## Summary

Samples of sweet sorghum were collected during 2007 and 2008 to evaluate their potential ethanol production. Juice yield and sugar concentration, biomass yield, and starch yield were measured from plant maturity to the killing frost. During 2007, samples were collected from Spindletop Farm in Lexington where a significant drought occurred that reduced the juice yield but significantly increased the sugar concentration within the juice. A single roll juicer was used that only extracted two-thirds of the soluble sugar. Assuming a more efficient system similar to what is employed by the sugar cane industry was used, between 5,000 and 6,500 l/ha (530 and 700 gal/ac) of ethanol could be produced using the juice alone. The maximum potential ethanol yield from corn would be no higher than 4,000 l/ha (420 gal/ac). In 2008, samples were collected from the Townsend farm near Mt. Sterling, KY. The potential ethanol yield from the juice varied between 4,000 and 6,500 l/ha (420 to 700 gal/ac). The larger field size likely resulted in larger variability between sampling dates. However, the juice yield was still higher than possible from corn starch ethanol. If starch and cellulosic ethanol are considered, sweet sorghum would likely produce between 50 and 100% more ethanol per acre than corn grain and stover.

There are a few disadvantages with sweet sorghum. The primary disadvantage is the short shelf-life of the juice. Due to the high sugar content, the juice cannot be stored. However, the addition of yeast under non-sterile conditions allowed for 95% of the sugar to be converted to ethanol. Fermenting the juice into ethanol on-farm would appear to be feasible; however methods to concentrate the ethanol into a more concentrated form would be required to reduce storage and transportation costs. In addition, the development of equipment for large-scale harvest of sweet sorghum is required. Overall sweet sorghum would appear to be a very feasible crop for ethanol production in Kentucky.

## Introduction

Currently the majority of US ethanol is produced from corn starch. Alternative crops and systems are available that could increase the production of feedstocks required for the manufacture of liquid transportation fuels. Ethanol from starch requires enzymes and heat to convert the starch to sugars that can be fermented. This is relatively easy but requires a large quantity of energy to dry the distillers' grain to be used as animal feed. Increased ethanol production from starch sources is probably not feasible for Eastern Kentucky. Sugar cane is an ideal crop for ethanol production since the juice from the stalk is high in sugar that it directly fermentable to ethanol. The closest crop that can be grown in Kentucky is sweet sorghum (Figure 1) that has been traditionally grown in small quantities in Central and Eastern Kentucky. Sweet sorghum is similar to sugar cane since the juice in the stalk is high in sugar and is readily fermentable.



**Figure 1. Sweet sorghum field (UK Agricultural Communications).**

The sorghum family, sweet sorghum and grain sorghum (milo), have numerous advantages relative to corn. Sorghum requires less nitrogen 60 to 90 lb/ac compared to 120 to 150 lb/ac for corn. One pound of N requires 18,000 Btu of energy to produce. Using the midpoint nitrogen application rate, sorghum and corn production requires 1.35 and 2.43 million Btu/ac for nitrogen fertilizer. Ethanol has an energy content of approximately 76,000 Btu per gallon. Assuming an ethanol yield of 400 gal/ac for corn and sweet sorghum, 30.40 million Btu/ac of liquid transportation fuels could be produced.

In addition, optimal corn yields require between 20 and 31 inches of water compared to sorghum that require between 18 and 26 inches of water. Although most of Kentucky averages over 40 inches of rainfall per year, our soils are typically shallow and require more consistent rainfall than the deep soils located in the Corn Belt. The lower water requirement of sweet sorghum is a significant advantage relative to corn.

The lower nitrogen and water requirements of sweet sorghum would significantly improve the energy balance of ethanol production relative to corn. Work by USDA has shown corn ethanol will produce 1.3 to 1.8 Btu of energy for every Btu of fossil energy. However, sweet sorghum is estimated to produce 12 to 16 Btu of ethanol for each Btu of fossil energy.

Management practices have been optimized for the production of sorghum syrup. For example, deheading sorghum early in the season eliminates grain production that can negatively affect syrup quality. However, the grain could be advantageous if the goal is ethanol production or as livestock feed. Sweet sorghum grain has similar starch content as grain sorghum and ethanol yields would be similar. In addition, the sweet sorghum stalks after juicing could be a valuable animal feed or feedstock for cellulosic ethanol conversion.

### **Objectives**

The project objectives were:

1. Measure the sugar content, juice yield, and fermentation efficiency from sweet sorghum varieties in Kentucky;
2. Investigate the influence of harvest date (from bloom to the killing frost) on the potential of producing sugar from sweet sorghum for ethanol production relative to corn; and
3. Characterize the bagasse residue after juicing for alternative value-added uses: feeding value to cattle, heating value for power, and as a feedstock for cellulosic conversion to ethanol.

### **Fall 2007**

Samples were collected from UK's Spindletop farm in a year characterized by a severe drought. Three varieties were tracked (Dale, Sugar Drip, and Simon) at two planting dates (May 10 and May 28). Samples were collected eight times (between September 25 and November 15). The plants were counted, grain head removed, juiced with a single roll juicer (Figure 2), volume of juice, and sugar content measured. After juicing the bagasse was split with a portion oven dried and a subsample ensiled in small PVC cylinders for six months (Figure 3). Bagasse composition was quantified using assays employed with other biomass crops. The only modification was the bagasse was soaked in hot water (45°C for 20 minutes) to determine the soluble sugar content.

Figure 4 shows the change in sugar content of the juice with the three varieties and the two planting dates. The sugar content of the juice was similar throughout the harvest season until the killing frost that occurred on November 7. The sugar content of the juice was significantly lower on November 7 due to the frost and was not detectable on November 20. Only data from the early plantings are reported. The late plantings had a final ethanol yield within 5% of the early plantings. Simon is not reported due to its very low ethanol production (approximately two-thirds lower than Dale throughout the year).

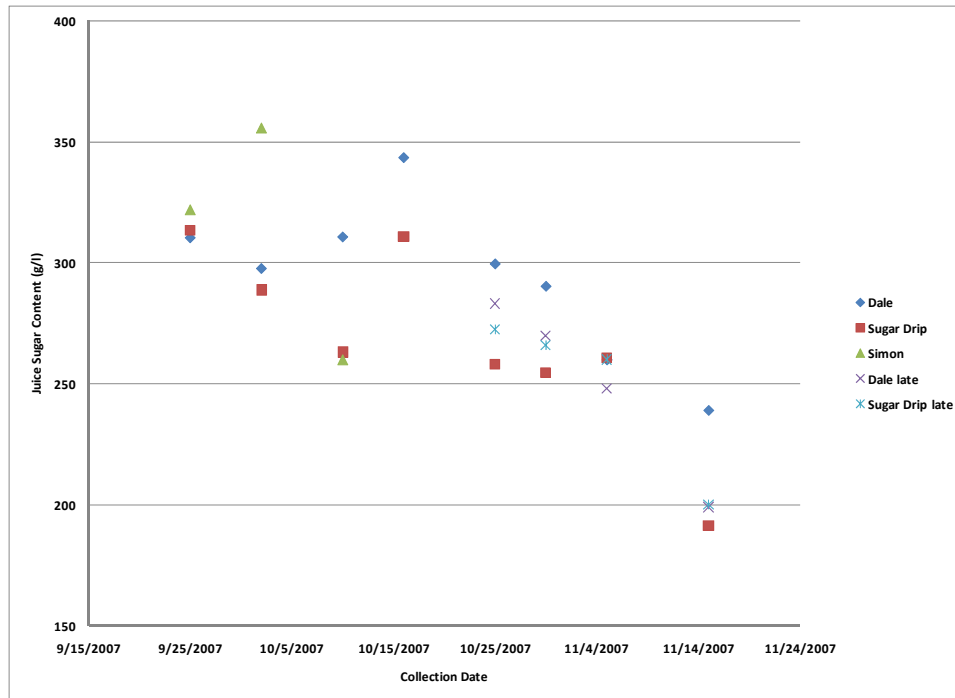


**Figure 2. Single roll juicer used for experiments.**



**Figure 3. Mini-PVC silos for ensiled storage.**

The total glucose content of the bagasse samples varied between 0.56 and 0.59 g glucose/g dry matter. Between 0.24 and 0.30 g glucose/g dry matter were soluble sugars that remained in the bagasse due to inefficient juice extraction. After ensiling the total glucose content decreased to a level between 0.44 and 0.49 g glucose/g dry matter, of this between 0.12 and 0.17 g glucose/g dry matter were still in the form of soluble sugars. The soluble sugar in the bagasse is directly related to the juice extraction efficiency. Sugar cane processors will frequently use three roll presses and hot water to maximize sugar extraction. The stalks in this study were juiced with a single roll press that could be optimized for increased sugar recovery in future designs.



**Figure 4. Sugar content (glucose, fructose, and sucrose) of the juice from early plantings of Dale, Sugar Drip, and Simon and late plantings of Dale and Sugar Drip during 2007.**

Figure 5 summarizes the potential ethanol production from each fraction of sweet sorghum (cellulose from the bagasse, starch from the grain, juice, and the residual sugar in the bagasse that could be extracted with improved juicing techniques). Two of the sampling dates were neglected due to missing data. Corn with a grain yield of 8.0 t/ha (150 bu/ac) and a stover yield of 8.0 t/ha is included for comparison. The highest average annual corn yield recorded in Kentucky was 152 bu/ac in 2004. It should be noted that at the Spindletop farm in 2007, the average corn yield was less than 125 bu/ac due to the drought so the hypothetical corn ethanol yields are high estimates.

Figure 6 and Figure 7 show the total quantity of material that could be produced using sweet sorghum. Previous research at UK showed a similar trend that Dale was a higher producing variety compared to Simon or Sugar Drip. The total tonnage of material produced using Dale was over 45 wet t/ha (20 wet ton/ac) throughout the sampling period. Between 35 and 45% of the total weight was readily extractable juice. It should be noted that the weights are as-is and a large portion of the weight was water.

The total potential ethanol yield (juice, cellulosic, and starch processed into ethanol) a maximum yield of over 8,000 l/ha (850 gal/ac) when using Dale should be possible (Figure 8). Compared to the total potential ethanol yield from corn (starch and cellulosic), sweet sorghum would appear to produce at least 33% more ethanol than corn. Further, a large portion of the ethanol produced using sweet sorghum would be from juice that has a high concentration of fermentable sugars.

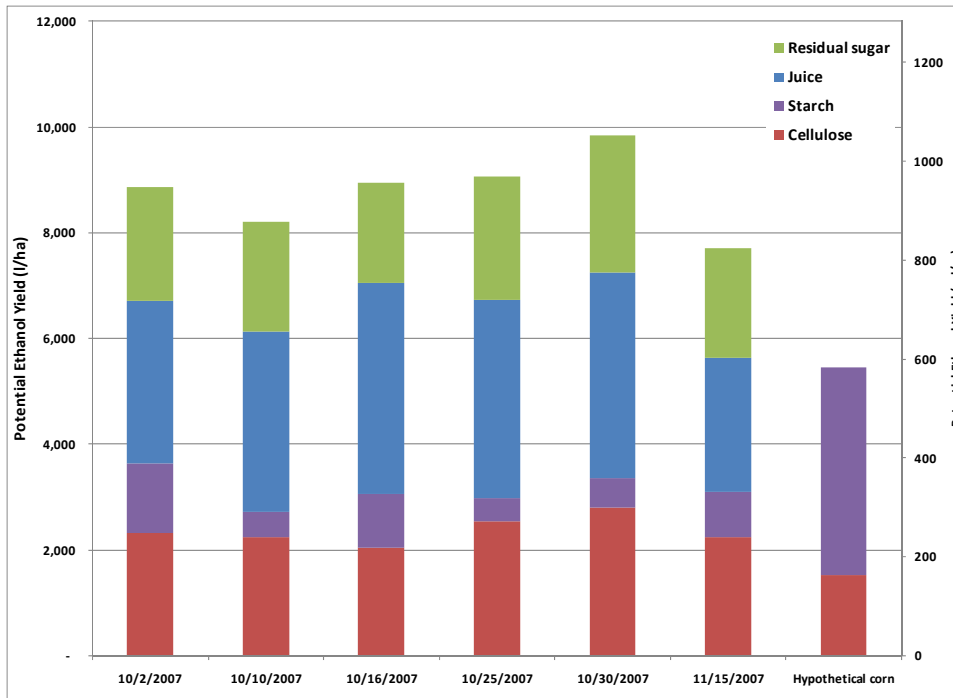


Figure 5. Potential ethanol yield from juice, grain, and ensiled bagasse of early planted Dale during 2007. Hypothetical corn is estimated using a grain yield of 8 t/ha (150 bu/ac) and a stover yield of 8 t/ha with an ethanol yield of 334 l/t (80 gal/ton).

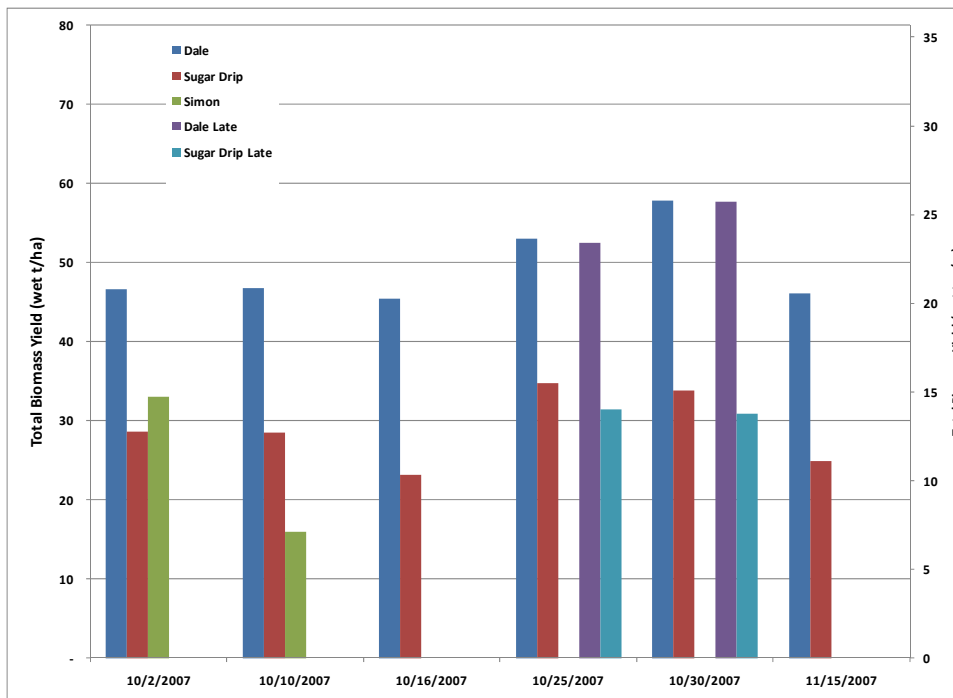


Figure 6. Total biomass yield from Dale, Sugar Drip, Simon and later plantings of Dale and Sugar drip in 2007. Note the tonnage includes the mass of moisture in the crop.

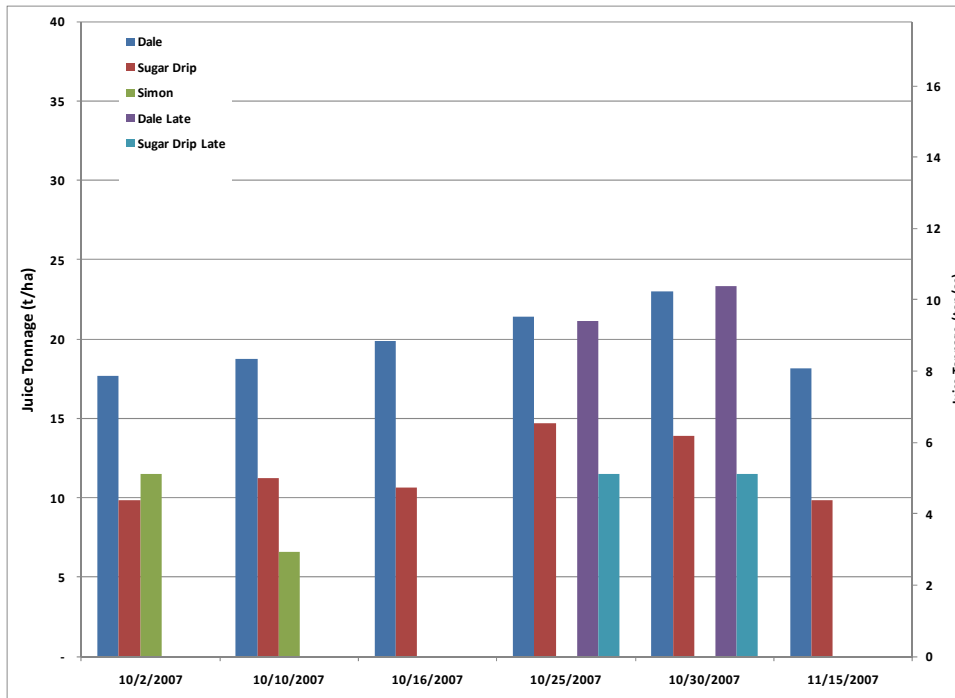


Figure 7. Juice yield from Dale, Sugar Drip, Simon and later plantings of Dale and Sugar drip in 2007.

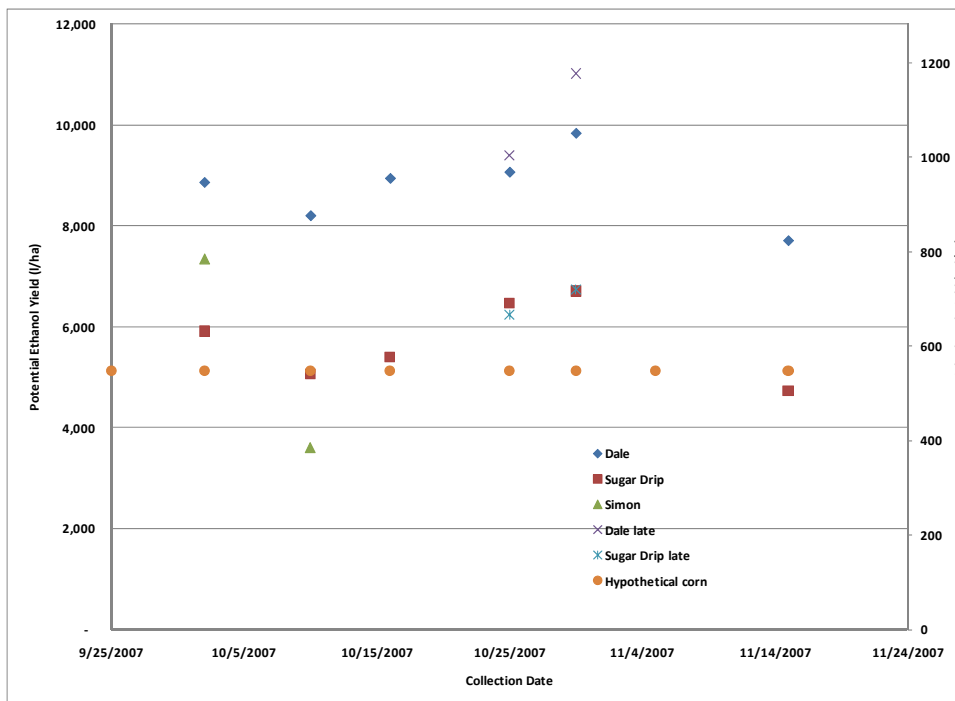


Figure 8. Total potential ethanol yield juice, grain, and ensiled bagasse of sweet sorghum during 2007. Hypothetical corn is estimated using a grain yield of 8 t/ha (150 bu/ac) and a stover yield of 8 t/ha with an ethanol yield of 334 l/t (80 gal/ton).

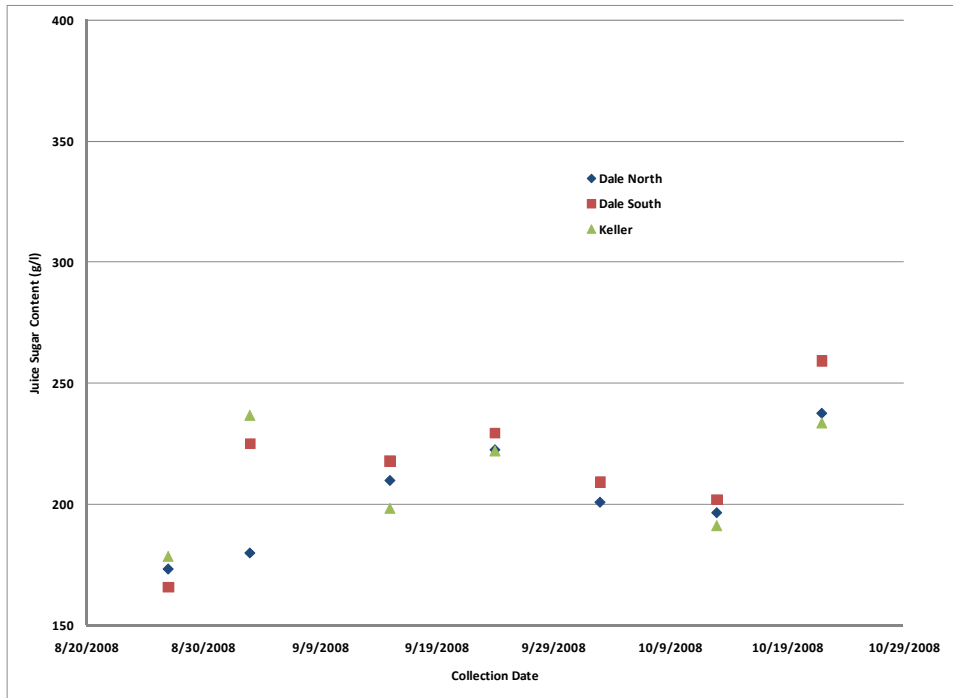
### Fall 2008 Data

Similar sampling procedures were followed during 2008. Eight plants were randomly selected in the field and the plant population determined. All samples were collected from a farm near Mt.

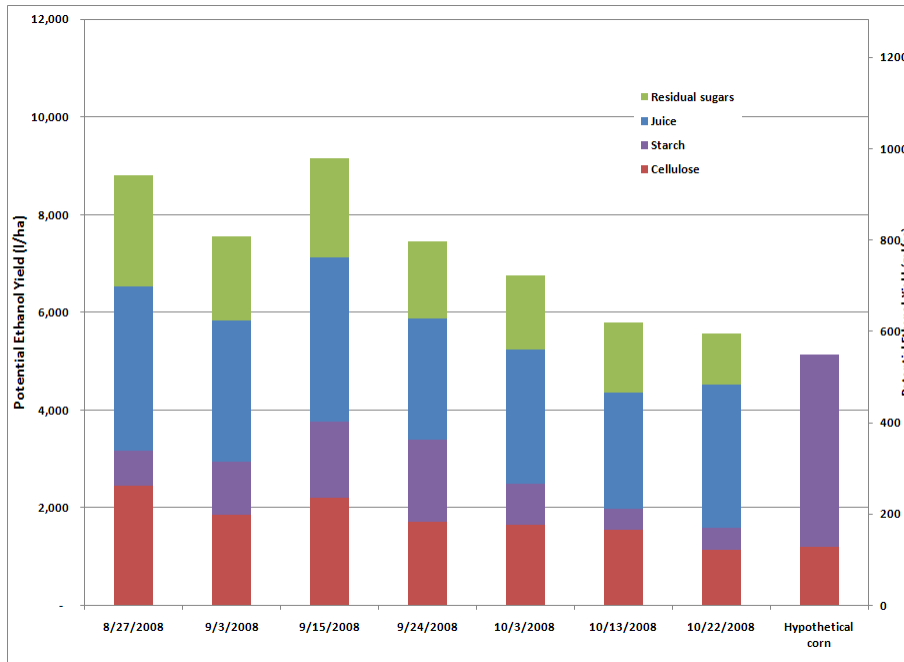
Sterling, KY (Townsend Farm). Due to the larger field size, there was additional variability between sampling dates. However, the field size was typical of what would be encountered during on-farm production of sweet sorghum in Central and Eastern Kentucky. The plant population was also more varied across the larger fields that led to greater variability in the estimated ethanol yield.

Figure 9 summarizes the sugar content in two fields of Dale (north and south) and one field of Keller. All of the fields were seeded within a one week time frame with a similar fertility and management program applied. One notable observation is the considerably lower sugar contents of the juice during 2008 relative to 2007. This was primarily due to the significant drought that occurred in 2007 that increased the sugar content of the juice. The results in 2008 would be considered more typical.

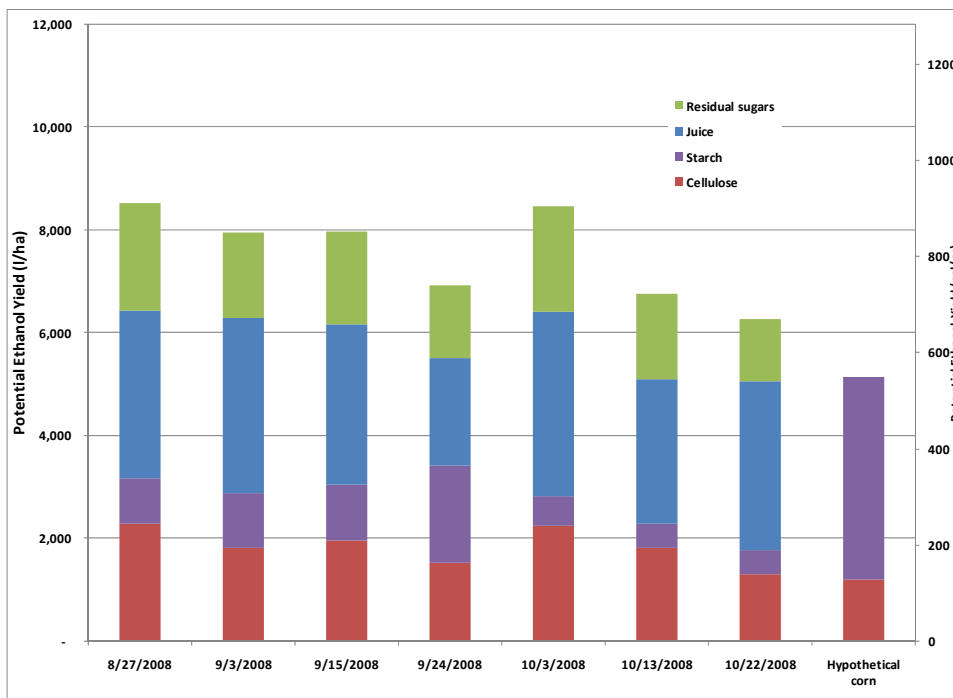
Figure 10, Figure 11, and Figure 12 show the potential ethanol production from the two fields of Dale and one field of Keller relative to corn. One interesting observation is the higher cellulose content of the sweet sorghum bagasse relative to corn stover. Some of the higher cellulose contents could be due to residual sugars, although all samples were washed with hot water and the sugar content analyzed. Sweet sorghum produces a small amount of grain and the potential ethanol yield from starch were considerably lower than corn. However, the potential ethanol production from the juice and residual soluble sugars were higher than the potential ethanol production from corn starch.



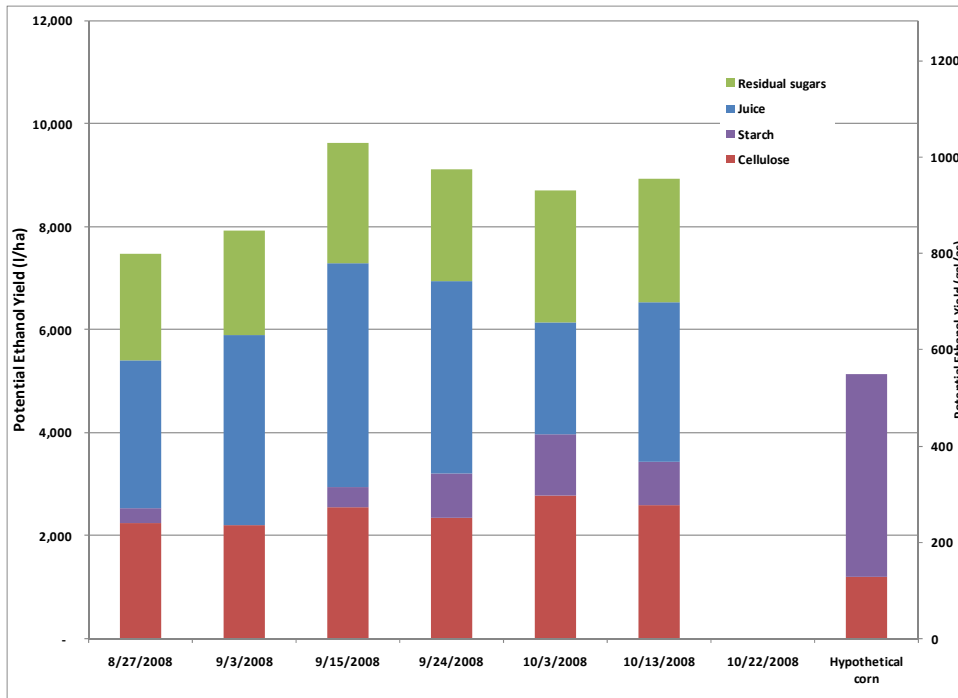
**Figure 9. Sugar content (glucose, fructose, and sucrose) measured in the juice during 2008.**



**Figure 10. Potential ethanol yield from juice, grain, and ensiled bagasse of Dale in southern field during 2008. Hypothetical corn is estimated using a grain yield of 8 t/ha (150 bu/ac) and a stover yield of 8 t/ha with an ethanol yield of 334 l/t (80 gal/ton).**

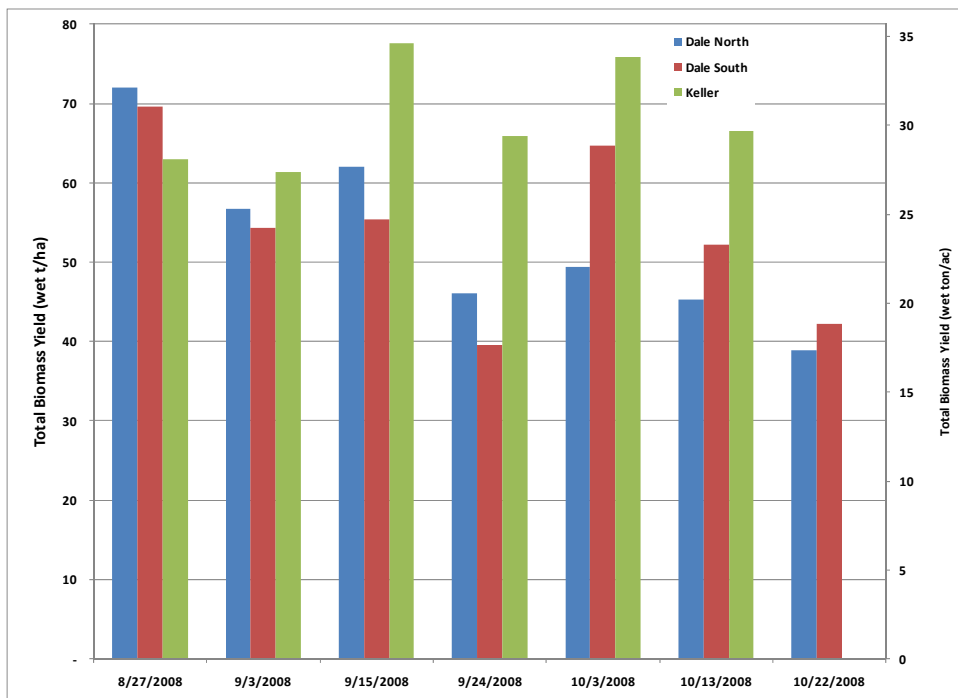


**Figure 11. Potential ethanol yield from juice, grain, and ensiled bagasse of Dale in northern field during 2008. Hypothetical corn is estimated using a grain yield of 8 t/ha (150 bu/ac) and a stover yield of 8 t/ha with an ethanol yield of 334 l/t (80 gal/ton).**

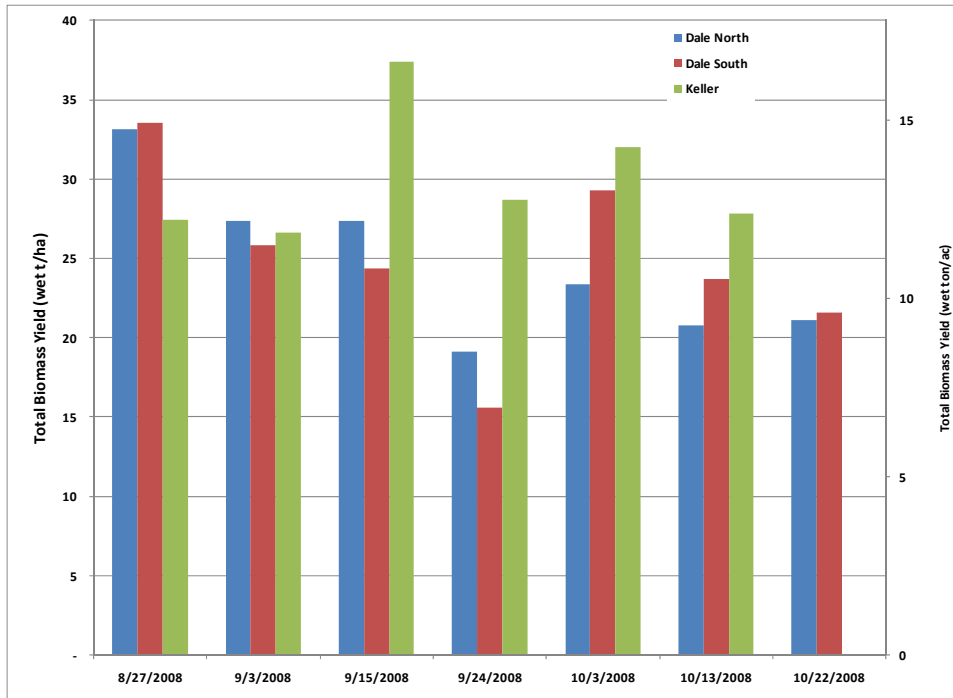


**Figure 12. Potential ethanol yield from juice, grain, and ensiled bagasse of Keller during 2008. Hypothetical corn is estimated using a grain yield of 8 t/ha (150 bu/ac) and a stover yield of 8 t/ha with an ethanol yield of 334 l/t (80 gal/ton).**

Figure 13 and Figure 14 summarize the total quantity of material that could be harvested from sweet sorghum. The weather was near normal during 2008 and Dale and Keller produced a tremendous quantity of material (over 40 wet t/ha or 14 wet ton/ac). The majority of the mass was due to water and soluble sugars. The total juice yield was frequently over 22 wet t/ha (10 wet ton/ac) throughout the harvest season.



**Figure 13. Total biomass yield from Dale, Sugar Drip, Simon and later plantings of Dale and Sugar Drip in 2007. Note the tonnage includes the mass of moisture in the crop.**



**Figure 14. Juice yield from Dale, Sugar Drip, Simon and later plantings of Dale and Sugar drip in 2007.**

**Potential Implementation**

Numerous juice samples during 2007 and 2008 were fermented to evaluate any potential hurdles. Prior to fermentation the juice was filtered and centrifuged to remove solids. Yeast from a commercial ethanol plant was used to perform the fermentation under non-sterile conditions with no temperature control. Complete fermentation took seven days due to the lack of temperature control, but nearly 95% of the sugar was converted to ethanol. Fermenting the juice on-farm would appear to be a feasible storage method for the juice. Due to the high sugar content of the juice, storage of the raw juice would likely be unfeasible.

The emphasis of this project is to develop renewable energy industries using non-traditional agricultural areas. Soil data from USDA was used to estimate the potential acreage available in Floyd, Johnson, Magoffin, Menifee, Morgan, Powell, Rowan, and Wolfe Counties. The total acreage in the eight counties is 1,438,857 acres. Estimated land productivity data from the USDA soil database (corn yield) was available for 196,272 acres and this was considered the only land capable of supporting sweet sorghum. According to the USDA soil database, the relative corn yield in the field used on Spindletop Farm was 122 bu/ac. The ethanol yield from sweet sorghum juice on the same field was a minimum of 400 gallons per acre and this is considered a conservative estimate. The estimated corn yield in the eight counties was multiplied by 400 gal/ac and divided by the 122 bu/ac for the soil at Spindletop. For example, Allegheny loam soils with a slope between 6 and 15 percent in Morgan and Magofiin counties have a base corn yield of 93.5 bu/ac. Potential ethanol production from that soil would be 307 gal/ac (400\*93.5/122). The estimated corn yield, land available and estimated ethanol production is summarized in Table 1. Obviously all of the land would not be used for sweet sorghum production. However, if 20% of the land was used 10 million gallons per year of ethanol could be produced.

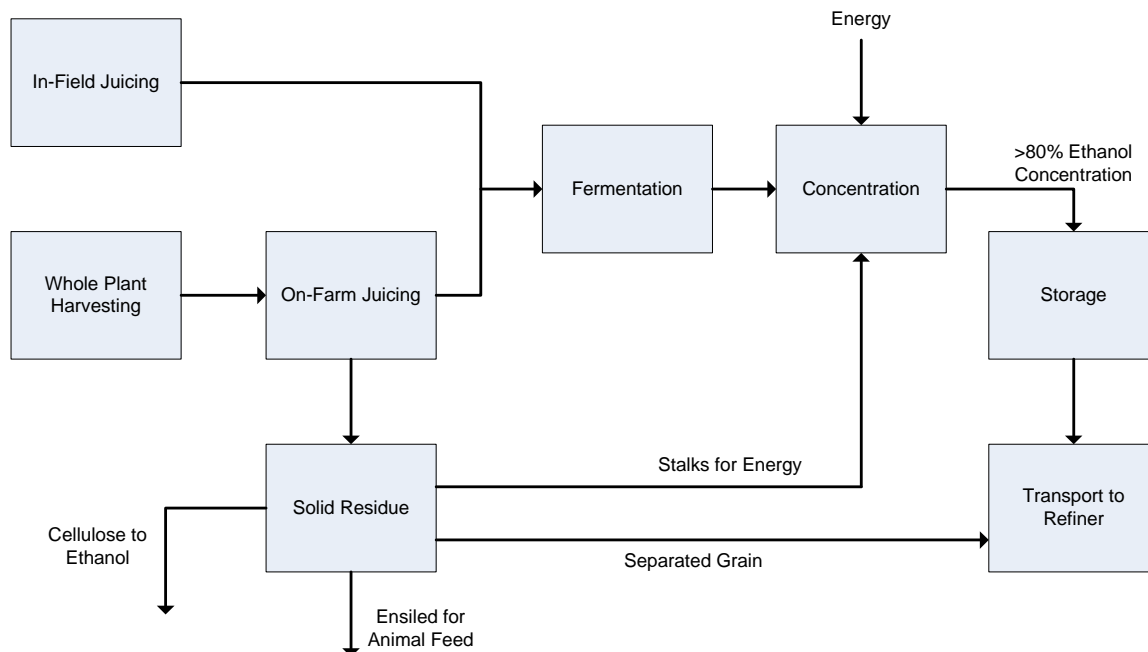
To put these numbers in perspective, Kentucky’s residents consumed 53,898,000 barrels of gasoline during 2004, or 538 gallons per person. Kentucky had a population of 4,206,024 and the eight counties (Floyd, Johnson, Magoffin, Menifee, Morgan, Powell, Rowan, and Wolfe Counties) had a population of 144,167 during 2006, or 3.4% of the total population. Assuming fuel consumption is evenly distributed throughout the Commonwealth, a 10 million gallon sweet sorghum to ethanol plant would provide 10% of the liquid fuel needs for the region (adjusted for the lower energy content of ethanol).

**Table 1. Estimated corn yield, acres available, and estimated ethanol yield from sweet sorghum juice for Floyd, Johnson, Magoffin, Menifee, Morgan, Powell, Rowan, and Wolfe Counties.**

Corn Yield (bu)	Land Available (acres)	Estimated Ethanol Yield (gal)
>110.1	2,884	1,068,531
100.1 to 110	11,052	3,667,655
90.1 to 100	48,212	14,803,699
80.1 to 90	50,676	14,019,388
70.1 to 80	25,416	6,132,721
60.1 to 70	30,698	6,685,607
50.1 to 60	27,334	5,184,875
Total	196,272	51,562,477

### Processing Options

There are a number of potential processing options for sweet sorghum (Figure 15). The stalks can be juiced in the field and only juice transported to the farm. An alternative option would be to chop the sweet sorghum into billets (similar to sugarcane) and transport the whole plant to the farm. At the farm, the grain could be separated and the stalks juiced. The juiced stalks (bagasse) could be ensiled with the grain for animal feed or used for heat to concentrate the juice. If cellulosic ethanol becomes feasible, the bagasse could also be used as a feedstock at a lignocellulose ethanol plant. Grain could be separated from the solid material and sold for ethanol production or animal feed.



**Figure 15. Processing options to convert sweet sorghum juice to ethanol.**

The main challenge is to remove the majority of the water to decrease the amount of storage required and minimize transportation costs. This could be done using a distillation or membrane system. Energy for the distillation system could be provided by combustion of wood products, juiced stalks or fossil sources. Fermenting the juice to ethanol or storing an ethanol solution does not pose major challenges.

Producing fuel-grade ethanol on individual farms would require some work to insure the proper taxes, permits, and safety considerations were properly handled. Although obtaining a license from the Bureau of Alcohol, Tobacco, and Firearms to produce alcohol is relatively easy (Form 5110.74). There are still a number of hurdles. The most feasible alternative would probably involve farmers producing an ethanol solution with a concentration between 70 to 90% that is transported to a centralized facility. Centralized facilities would be responsible for producing anhydrous ethanol, denaturing the ethanol, and marketing issues.

### Example Farm Operation

Assuming a farm was producing 200 ac/yr, with a harvest window of 80 days, and a field efficiency of 80%, 3.1 ac/day of sweet sorghum could be harvested. If the juice yield was 4,000 gal/ac, 12,500 gal of juice per day would be handled, or the equivalent of 1,343 bu/day. A juice yield of 4,000 gal/ac would require 95% of the juice to be extracted using the press. This is roughly the sugar recovery found with sugar cane. Assume After fermentation the ethanol concentration is approximately 10%, after concentrating to 80% the total quantity stored would be 100,000 gallons (approximately the size of a small grain bin - 10,700 bu). A low cost method of storing and fermenting the juice could be a used shipping container with a rubber bladder for storing liquids. These bladders are frequently used in shipping containers to store drinking water or diesel fuel for the military. A used shipping container with the bladder would cost approximately \$0.30 per gallon. Numerous options would be available for developing low cost systems in rural areas.

Current ethanol prices are \$2.30/gal, producing 10 million gallons per year could result in the residents of the eight counties retaining 23 million dollars a year in their local communities.