THE FEASIBILITY OF GROWING SWEET SORGHUM

FOR THE ON-FARM PRODUCTION OF

ETHANOL IN OKLAHOMA

By

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CHAPTER I

PROBLEM STATEMENT

The Energy Policy Act of 2005 includes a provision designed to double the production and use of ethanol in fuels by 2012 (Ragen and Kenkel, 2007). This will greatly increase the demand for ethanol feedstock such as corn and grain sorghum. Many alternative feed stocks are being researched to address increasing ethanol demand. Because of its high fermentable sugar content, sweet sorghum could be used for the production of ethanol (Hallmark, 1984). The environment in Oklahoma is suitable for growing sweet sorghum, which is a warm season hardy grass with good drought and heat tolerance. Is it economically feasible to grow sweet sorghum and produce ethanol on-farm from sweet sorghum in Oklahoma?

If it is economically feasible to grow sweet sorghum for ethanol production, this could provide an additional income stream for farmers in Oklahoma from on-farm production of ethanol. If it is not economically feasible to grow sweet sorghum for ethanol production, then farmers in Oklahoma can avoid investing money in a non-profitable venture.

Objectives

This research will determine the economic feasibility of growing sweet sorghum for small-scale, on-farm ethanol production in Oklahoma.

The specific objectives of this research are to:

1. Determine the Break-Even price per ton of sweet sorghum to make ethanol production feasible.
2. Determine the cost of pressing, fermentation, distillation, storage, and transportation of ethanol produced from sweet sorghum.
3. Determine the sensitivity of specific objectives number 1 and 2's (above) break-even prices to changes in laws and regulations that affect the production of small-scale, on-farm production of ethanol from sweet sorghum.

CHAPTER II

LITERATURE REVIEW

Background

Sorganol™ is defined as the process for in-field production of ethanol from sweet sorghum which was suggested by Lee McClune (Bellmer and Huhnke, 2007). The main advantage in producing ethanol from sweet sorghum as opposed to corn is the fact that sweet sorghum is a low input producer of carbohydrates in a form that is ready to be fermented and distilled. Corn on the other hand is a starch-based crop that requires an expensive heating process to convert the starch into simple sugars (Jacoby, 2007). Sweet sorghum provides high biomass yield with low irrigation and fertilizer requirements. Corn ethanol requires high amounts of water not only for growing but also for processing during the phase that changes the starch into carbohydrates (Stotts, 2007).

Ethanol production has increased to more than four times the amount of ethanol produced ten years ago in the mid 1990's. In early 2007, there were 118 ethanol plants operating in the United States with 60 more under construction. Corn-based ethanol production has been profitable over the past few years with help from government subsidies. Recently, near doubling of corn prices has hampered this profitability (Outlaw, et al., 2007).

The name “sweet sorghum” is used to identify varieties of sorghum, Sorghum bicolor (L.) Moench, that are sweet and juicy (Bitzer, 1991). Sweet sorghum is a C4 grass with wide flat leaves and a rounded head that is full of grain at maturity. It is believed to have first been grown in Africa (Kundiyana, 1996). Sweet sorghum is grown mostly in the south-eastern United States but extends to Texas in the gulf states, all the way north to Wisconsin, and west to Kansas, Iowa, and Minnesota (N.S.S.P.a.P.A., 2007). Sweet sorghum contains a higher sugar content compared to grain sorghum, which is a closely related crop. Sweet Sorghum is extensively used in the production of syrup. The sweet sorghum seed can either be a annual or short perennial crop (Gnansounou, et al., 2005).

Soil

To raise a healthy crop, having fertile soil is important. Loam and sandy loam soils are the best suited for growing sweet sorghum. Since these soil types have bigger particle sizes, water will soak into them, leaving the soil drier after a rain than thicker and heavier soils will. Sweet sorghum will thrive with sandy loam and loam types of soil since it will not be flooded. Also, other crops struggle in this type of soil due to lack of moisture, so sweet sorghum has a distinct advantage over those crops in this type of soil. While soil drainage is important, it is also crucial to have good rainfall during the growing season of sweet sorghum. While sweet sorghum is drought resistant, the more moisture it has, the more it will thrive. Crop residue, the remainder of the previous crop left on top of the soil after harvest, will also help to improve the water holding capacity of the soil (Bele, 2003). These large particles of residue slow down water on its way into the soil. Sweet Sorghum is very tolerant of humid environments. Heavy soils that warm slowly in the spring are not suitable to raise sweet sorghum.

Sweet sorghum is very sensitive to soil acid, the soil pH should be greater then 5.8 (Bele, 2003). In Oklahoma, the average soil pH is 5.9 in tests that were run in the years 2000-2003. One quarter of more then 40,000 samples (10,000 samples) had a pH of less then 5.5, posing production problems do to soil acidity (Zhang, 2003).

Crop Rotation

Sweet sorghum fits in well with rotations of crops such as cotton, corn, and wheat. Crop rotation usually helps to increase yields of crops due to the fact that some crops take certain nutrients out of the soil while depositing other nutrients into the soil. Cotton works well in a rotation because it leaves the field clean due to the fact that the cotton has to be stripped (harvested) with no weeds in the field (Bele, 2003). While cotton leaves a clean field, it also leaves large pieces of residue in the form of woody stalks. In no-till situations, these woody stalks can provide cover to prevent the soil from blowing, protecting the valuable topsoil. Corn, cotton, and sweet sorghum all work well in a rotation together because they all have the same growing seasons; all three crops are planted in the spring and harvested in the fall (and sometimes winter for cotton). Therefore, it is possible to plant one crop (corn, cotton) on the land in year 1 and rotate a different crop (sweet sorghum) on the same land in year 2.

Wheat is the grain crop that occupies the most acres in Oklahoma. In 2006, wheat was planted on 3.4 million acres in Oklahoma, followed in second place by cotton at 320,000 acres and soybeans at 310,000 acres (USDA, 2006). The rotation system for wheat will be a little different. This is due to the fact that wheat is planted in the fall and harvested in the summertime (mainly June in Oklahoma). In year 1, wheat can be planted in the fall, and harvested the following summer (year 2). After the wheat is harvested,

sweet sorghum can be planted (a short season variety) to double-crop the land. This is not recommended since the harvest window will be very short before the freeze in the fall of year 2. Instead of planting sweet sorghum after wheat harvest in year 2, wait until early spring of year 3 to plant the sweet sorghum. Harvest the sweet sorghum in the early fall of year 3 and after that replant the field to wheat. This gives the soil more summer fallow time to replenish lost moisture and break down nutrients. Rotations for other fall planting crops used in Oklahoma, such as canola, would be very similar.

Varieties

Recently, tests have been run in Oklahoma to gauge the yield differences between varieties of sweet sorghum. Five different varieties were tested including Theis, M81E, Dale, Topper, and Keller. This test used a one-month harvest window and tested the yield difference within this window by variety. The first harvest date was mid-September and the second harvest date was mid-October. Later tests could use a wider harvest window to test the effects of being able to harvest sweet sorghum over several months. The five locations included in this test were Haskell, Fort Cobb, Stillwater, Perkins, and Poteau (Bellmer and Huhnke, 2006). The results are in Table II-1.

Table II-1. Average sweet sorghum yields at two different harvest times at 5 locations in Oklahoma (Bellmer and Huhnke, 2006).

	Average Biomass Yield (tons/acre)			
Location	High Yield Variety (Harvest 1)	Wet Yield (tons/acre)	High Yield Variety (Harvest 2)	Wet Yield (tons/acre)
Haskell	Dale	25.8	Topper	25.7
Fort Cobb	Topper	25.6	Topper	24.5
Stillwater	Dale	24.1	M81E	28.1
Perkins	Theis	16.7		
Poteau			M81E	28.6
Goodwell			M81E	30.8

Dale is an early maturing variety that can be planted and harvested at the beginning of the harvest window. Dale is resistant to stalk red rot, which can be damaging to sweet sorghum. Theis is a late maturing variety, so it can be harvested at the end of the harvest window. Theis' other feature is its resistance to lodging. This is very useful in a late maturing variety. M81-E is susceptible to light frost and is also a late maturing variety. Finally, Topper has decent resistance to grey leaf spot, zonate leaf spot, rough leaf spot, and twisted top (M.S.U.).There are several other varieties of sweet sorghum including Sugardrip, Wiley, Cowley, Sart, Tracy, Brandes, Honey, Georgia Blue Ribbon, and Williams.

There have been many tests run in Louisiana at the St. Gabriel Research Station, which is 10 miles south of Louisiana State University's campus in Baton Rouge. While these tests were conducted in Louisiana and not Oklahoma, the results could provide some evidence to help base future research within Oklahoma. The first of the Louisiana

tests, which used M81E, Wray, and Cowley, found that due to a higher stalk yield in M81E, the total sugar and alcohol yields per acre were similar with Wray and M81E and these were both higher then with Cowley (Ricaud, 1989). Another test was run a year later which involved the same three varieties being planted. These tests showed the stalk and biomass yield were highest in M81E and lowest in Cowley, and the total sugars and alcohol yields per acre were highest in Wray and lowest in M81E (Ricaud, 1990). The first two tests show Wray as a common variety to produce a plant that is high in total sugar and alcohol yield. The variety Mn1500 has also been tested in comparison with Wray and Theis. Mn1500 was a late maturity plant and has high sugar and alcohol yields when compared to the other two varieties (Ricaud, 1981). This variety could be planted at the same time as other varieties and harvested later, therefore extending the harvest window.

Planting

Tests have been done to investigate the effects of planting dates on the yield of sweet sorghum. In field tests run in Louisiana, it was found that stalk and sugar yields from crops planted March 15th and April 15th were similar to one another and significantly higher than the plants that were planted on May 15th (Ricaud and Marshall, 1969). This shows that planting at the earliest possible time, when the soil temperature is warm enough in the spring, will provide the highest stalk and sugar yields. In the same field tests, it was found that stalk yield was not affected by the plant populations. The percent sucrose and sugar yield was increased with increasing plant populations.

There have been tests that were run in more recent years (2007) within the state of Oklahoma. These tests found that sweet sorghum could be planted as early as mid-April,

and with staggered plantings for 2-3 months, could be harvested from August all the way through November at seed maturity. These tests were carried out at six different locations around the state of in 2007. The six locations used in 2007 by Oklahoma State University include Goodwell, Lane, Haskell, Fort Cobb, Stillwater, and Altus. These tests showed a longer growing period produced a higher yield. For example, in Haskell, OK, the crop planted on April 20, 2007, had an average yield of 36.67 wet tons per acre, whereas the crop planted on May 16, 2007 yielded 23.84 wet tons per acre. Both crops were harvested on September 21, 2007. In Fort Cobb, OK, fields were planted on May 14, 2007. The first crop was harvested on September 24, 2007 and yielded 13.32 wet tons per acre. The second crop was harvested on October 31, 2007 and averaged 18.96 wet tons per acre (Bellmer and Huhnke, 2008).

Row spacing ranges from 8 inches when drilled to 42 inches when planted. A depth of 1 inch is recommended, going deeper for sandy soils and shallower for heavy soil (Mask and Morris, 1991).

Fertilizer

Oklahoma State University tested in 2007 to see the effects of pre-planted nitrogen rates versus top-dressing nitrogen and the effects on yields. The Dale variety was planted on June 5, 2007 at the Lake Carl Blackwell field test location and harvested September 28, 2007. The results are in Table II-2.

Table II-2. Nitrogen Impacts on Sweet Sorghum Yield.

Pre-Plant Nitrogen	Top-Dress Nitrogen	Wet Yield (tons/acre)	Standard Deviation
0	0	23.7	4.4
0	50	28.1	3.7
50	50	32.8	3.1
50	100	28.5	1.2
100	0	28.7	2.4
100	50	28.8	0.5
150	0	34.2	4.2

There have been other tests to compare the effect of these different fertilizers to see their impact on yields of sweet sorghum. The results showed that the sugar and alcohol yields per acre increased with 90 lbs. per acre of nitrogen, but increases from a high nitrogen rate and from potash were not significant (Ricaud, 1990). Each fertilizer treatment produced more sucrose and total sugars than the control, which had no fertilizer. The fertilizer combination (N-P2O-K2O) of 180-0-80 produced the highest total yield (tons/acre) (Ricaud, 1990). Other projects have suggested 20-20-20 to try and lower the costs of the fertilizer inputs. This application would provide 40 lbs. of each (N-P2O-K2O) per acre. In the specific experiment, it was assumed that the cost of the previously stated 20-20-20 fertilizer and custom application would be $5.82 per acre (Bele, 2003). Sweet sorghum crops grown after legumes such as soybeans and alfalfa may not need any nitrogen applied since legumes naturally fix nitrogen into the soil. This can reduce or eliminate the expense of nitrogen. Soil tests should be conducted to see if

additional lime, phosphorus, potassium, calcium, or magnesium should be added to the soil (Mask and Morris, 1991).

Ethrel is a treatment that is used mainly in the sugar cane industry to increase sugar yields, but it can also be used with sweet sorghum to increase the sugar content of the plant. In tests that were run with the Wray, Theis, and Mn1500 variety, only Theis showed an increase in the percent of sugar in the plant as a result of the application of the Ethrel (Ricaud, 1981).

Weed Control

There are no herbicides labeled to use on growing sweet sorghum. The best alternative to herbicides would be the use of a cultivator. It may take 2 or 3 passes with a cultivator to clean a field. Also, avoiding planting sweet sorghum in excessively weedy fields is recommended (Mask and Morris, 1991).

Harvesting

Deciding when to harvest a sweet sorghum crop is a difficult decision but it is essential to getting the highest possible yield. The seed head will approach a soft to hard-dough state of maturity, indicating a good time to harvest. This stage is prior to the seed being ripe, when the seed is hard and firm and cannot be cut using a fingernail (Bitzer and Fox, 1992).

There have been many attempts at trying to make a harvester that would be useful to process sweet sorghum. One of the main problems encountered in the production of a harvester is the ability to deal with the inconsistency of sweet sorghum plants. Four input variables affect the crop conditions including variety, plant population, weather, and the

field condition (Cochran and Ricaud, 1985). When harvest time comes around prior to seed maturity, which is usually August through November in Oklahoma, these four input variables affect the type of crop harvested. Sweet sorghum plants at harvest differ in terms of plant height, lodging of the crop (laying down on the ground), and if the stalks are bent or straight (Cochran and Ricaud, 1985). These inconsistencies make it difficult to manufacture a single harvester that will work in all scenarios.

Combine harvesters which are used to harvest sugarcane can be used to harvest sweet sorghum. The combine harvester cuts sugarcane stalks into 12-14 inch billets, removes extraneous matter, and deposits the billets into wagons running beside the harvester. A primary advantage of harvesting green sugarcane is that the harvester deposits extraneous organic matter in a layer on the field. This contributes to moisture conservation, weed control, and cost savings in cultivation. Another advantage of the combine harvester for sugarcane is that high percentage of cane recovery in the field, particularly in lodged or down sugarcane (Salassi and Champange, 1996). With a combine harvesting system, a tractor pulling some type of self-dumping wagon runs parallel in the field beside the harvester. The combine cuts one row of cane per swath at a rate of 55-60 tons per hour.

Another option to harvest the sweet sorghum would be a self-propelled forage harvester. John Deere recently introduced some new models, with performance data available in Table I-3.

Table II-3. John Deere Self-Propelled Forage Harvester Models.

Model	Engine Displacement (Liters)	Max Horsepower (1900 rpm)
7250	9.0	382
7350	13.5	479
7450	13.5	556
7550	13.5	623
7750	13.5	623
7850	15.0	689

John Deere's new models have high horsepower numbers. This will provide extra horsepower to chop the sweet sorghum when it is still wet into small billets (1-2 inches) for later processing. The models are designed with cooling packages to stand up to the rigorous field conditions and long working hours. Crop flow is extremely important to overall harvesting productivity and the self-propelled forage harvesters are designed with an efficient system to cut and harvest the crop. Radial arc stainless steel feed-rolls deliver the crop to the cutter-head for chopping. The cutter-head with segmented knives cuts the crop into consistent lengths. A crop accelerator ensures steady processing for consistent trailer-loading (Nelson, 2007).

Other machines were used in research experiments to harvest sweet sorghum. One whole stalk harvester model that could be pulled by a low horsepower (67 horsepower) tractor was created that contained 4 main parts: the gathering belts, the flipper, the cross conveyer, and the accumulator (Rains, et al., 1990). The majority of the problems with this machine came when the flipper could not properly pass the sweet sorghum stalk onto

the conveyer (Rains, et al., 1990). Next, a machine was manufactured that was the same as the previously mentioned model but had the errors worked out. This machine would cut 3.9 acres a day as a single row-unit. The accumulator would gather whole stalks for a while and needed to be dumped every 81 seconds into windrows to be processed later (Rains and Cundiff, 1993).

Processing

After a harvester cuts the sweet sorghum, the plants still need to be processed. The first step in this process is juice expression. Sweet sorghum stalks harvested fresh in experiments have a moisture content of about 75% (Cundiff and Worley, 1991). The goal is to increase ethanol production and this is done by producing the greatest amount of juice from the sweet sorghum stalks during pressing. 50-100 tons of pressure should be applied to the stalks when they pass through rollers to express the juice. For 100 lbs. of whole sweet sorghum stalks, about 55 lbs. of juice will be extracted in an efficient system (Mask and Morris, 1991).

Experiments have been run to test the storability of sweet sorghum. Chopped stalks must be processed in a matter of hours if sugar yield is to be maintained (Eiland, et al., 1984). Nonstructural carbohydrates are lost within hours of harvest when the sweet sorghum is cut with a forage harvester. This nonstructural carbohydrate is preserved if the integrity of the stalk is maintained. Even whole stalks that are stored for 30 days are found to have a lower amount of nonstructural carbohydrates than ones that are processed immediately (Rains and Cundiff, 1993).

Fermentation

Fermentation is an oxidation-reduction reaction where some atoms donate electrons and become more reduced while other atoms receive electrons and are oxidized. It is an internally balanced reaction. Energy is produced in the step called phosphorylation (Kundiyana, 1996).

The fermentation process must begin quickly after harvest. The effect that temperature has on the fermentation process is being studied at Oklahoma State University. If temperature has a minimal effect on fermentation, then the juice can be fermented on a commercial scale at the site where it is harvested. New yeast strains are being tested to discover their optimal temperature range. Initial experiments investigated the use of temperature tolerant yeast strains with results indicating the fermentation is possible and that little or no pretreatment of the juice is necessary (Jacoby, 2007).

Regulations

With the production of ethanol comes a lot of responsibility, and the government has regulations set in place for producers of ethanol. These regulations mainly try to keep too many pollutants from affecting the environment. If a producer of ethanol is considered a minor source of pollution, then they are usually subject to only minor source permits or are permit exempt. This includes producers that omit less than 100 tons per year of any regulated air pollutant, 10 tons per year or less of any one Hazardous Air Pollutants, or 25 or less tons per year of any combination of Hazardous Air Pollutants (Ferrell, 2008). All major sources have to get appropriate permits from the Air Quality Division. For new sources or modifications of old ethanol sources, a Construction Permit

is required. After construction is complete, an Operating Permit is required and a demonstration is used to make sure that the operation emits pollutants as it was scheduled to do. A further classification of major or minor source is then applied to the ethanol producer based upon the potential to emit after the demonstration. If it is unclear whether or not you need a permit, applications can be made to test certain situations to avoid legal problems (Thompson, 2007).

After the sweet sorghum is processed, juice is expressed, fermented, and distilled; there will be wastewater containing some potential amount of ethanol that must be dealt with. There are three ways to dispose of this wastewater: by discharging the water in local waterways, by transferring the water to a local sewage plant to be treated, or by irrigating the wastewater onto farm ground. If wastewater is going to be dumped into waters of the state, a National Pollutant Discharge Elimination System permit must be acquired. This permit limits the quantity of pollutants in wastewater discharges and establishes other requirements. The National Pollutant Discharge Elimination System is used to protect the public's health and the aquatic environment (Ferrell, 2008). Wastewater can also be run through the local sewage system for treatment at a local sewage plant. Caution must be taken when using this method, since publicly owned treatment plants can not always handle all of the substances in wastewater. Local and state governments can determine if wastewater from ethanol production from sweet sorghum will affect local publicly owned treatment plants (OhioE.P.A., 2007).

CHAPTER III

METHODS

Farmers desire to gain the maximum potential profit from their operation. They tend to produce the crops, livestock, or combination of the two that have the greatest potential to provide a reasonable rate of return. Resources available to farmers include land, labor, capital, and management skills. Farmers combine these resources, using capital to obtain inputs and technology, to produce commodities and hopefully generate a profit.

The primary objective of this research endeavor is to determine the economic feasibility of ethanol produced on-farm from sweet sorghum in Oklahoma. The profitability of on-farm ethanol production from sweet sorghum is a function of sweet sorghum yield and harvesting costs, the costs of extracting the juice from sweet sorghum, fermentation and storage expenses, and distillation of the fermented juice to obtain fuel-grade ethanol. Additionally, profitability and overall feasibility are impacted by the limitations created by and costs associated with regulatory compliance for ethanol production.

Feasibility = f (production costs, processing costs, regulations, yield, output prices)

Production Costs

This cost category includes all of the farm production costs for producing sweet sorghum. The production costs are used to determine the break-even price per ton of sweet sorghum that will be used for the extraction of juice and eventually the production of ethanol. Several variables will affect the break-even price for an acre of sweet sorghum production, including: yield, seed costs, fertilizer costs, harvesting costs, machinery operations (field work) costs, and land rental costs. The break-even price represents the minimal price a farmer could accept to cover their costs of production, not including returns to management. As the costs per acre increase, break-even price per acre increases. As the yield per acre decreases, break-even price per acre increases.

Processing Costs

Processing costs consist of all costs associated with processing the billets of sweet sorghum. The processing costs include pressing, fermentation, distillation, storage, and transportation costs. The processing cost per gallon of ethanol will increase with an increase in any of the sub-costs of processing.

Laws and Regulations

Regulatory compliance will have a major impact on the feasibility of growing sweet sorghum for on-farm production of ethanol in Oklahoma. There are many laws that have been set up for the production of ethanol that are related to consumption-grade alcohol and fuel-grade ethanol production. Any law or regulation that increases the costs of production will negatively impact the feasibility of growing sweet sorghum for the on-farm production of ethanol in Oklahoma.

CHAPTER IV

PROCEDURE

Sorganol™ Process Design and Layout

The overall process will include all of the activities for producing non-denatured and fuel-grade ethanol from sweet sorghum. First, a sweet sorghum crop will be grown on ground prepared in the springtime. This preparation includes tillage work and fertilizer application. The sweet sorghum crop will then be planted and cultivated. Next, the crop will be harvested in the fall (August through November) with a forage harvester which will chop the sweet sorghum into small billets and throw them into a semi-truck which runs alongside the forage harvester. Then, the semi-truck loaded with sweet sorghum billets will deliver the billets to the processing location.

At the processing location, the billets will be pressed in a screw press to extract their juice. This pressing will produce sweet sorghum juice and bagasse (or silage) which will be sold for cattle feed. Next, the juice is placed into a storage bladder for further processing. Before 24 hours has passed, yeast is added to the storage bladder to ferment the juice. After three to four days (usually three) have passed, the juice is ready for distillation. Since fermentation takes up to four days, it is recommended that five to six large (50,000 gallons) storage bladders are available, one to receive non-fermented juice from the screw press, four for fermenting juice, and a final storage bladder for a spare.

After the juice is fermented, it is ready to be distilled. The distillation unit will have a daily inflow capacity that is greater than the maximum amount of sweet sorghum juice that can be pressed by the screw press in a day. This will allow the distillation unit to stay ahead of the screw press, therefore only requiring storage of juice that is either recently pressed or being fermented (less than 4 days of fermentation). If the screw press could process sweet sorghum billets quicker than the distillation unit could distill the fermented juice, than storage would be required for juice that has been fermented for more than four days. When distillation has taken place, non-denatured ethanol, which is fuel-grade, is produced as well as wastewater.

To dispose of wastewater, either a city wastewater (municipal) system is used or an irrigation system can be used to spread the water onto future crops. A final small (10,000 gallons) storage bladder is needed here to store the fuel-grade non-denatured ethanol until it can be transported by another semi-truck (7,300 gallon capacity) to a market where it will be blended with gasoline.

Data was gathered from several sources to create two spreadsheets utilized in this feasibility study. The first spreadsheet relates to sweet sorghum production. It is a summary of a crop budget that simulates all aspects of raising the crop of sweet sorghum, from the pre-planting field work through harvesting the crop. The second spreadsheet simulates the costs associated with processing sweet sorghum, from hauling the harvested crop to the press through final delivery of the ethanol and sale of silage from the bagasse. Also, the second spreadsheet incorporates the costs and benefits resulting from ethanol production regulations, tax credits, and policies that may affect the production of sweet sorghum for on-farm production of ethanol in Oklahoma.

Spreadsheet 1: Sweet Sorghum Production, Crop Budget with Cost Distribution

In the Production Spreadsheet, a budget was derived from costs that were assumed in the production of sweet sorghum. These costs were used to calculate break-even price distributions for producing different sweet sorghum varieties with differing levels of nitrogen application.

Table IV-1. Sweet Sorghum Production Budget Summary

	Units	Value (Standard Deviation)	Source
Yield	tons/acre	24.90 (8.15)	2006 & 2007 Sweet Sorghum Trials from Oklahoma State University
Seed	$/acre	$21.00	Kerr Center Budget
Fertilizer	$/acre	$92.91	2006 & 2007 Sweet Sorghum Trials from Oklahoma State University
Custom Work	$/acre	$53.84	Oklahoma State University CR-205
Custom Harvest	$/acre	$43.58	William Lazarus, University of Minnesota
Rent	$/acre	$30.21	Oklahoma State University CR-230
Total Cost	$/acre	$241.54	

Table IV-1 provides the assumptions used to generate the range of costs for producing sweet sorghum. These assumptions are backed by published research findings, communications with professors, and data collected from recent studies.

Yield

The yield data comes from data gathered at Oklahoma State University in 2006 (Bellmer and Huhnke, 2007) and 2007 (Bellmer and Huhnke, 2008). The data includes

tons of sweet sorghum per acre as well as nitrogen input used at 6 different locations across Oklahoma. These numbers were put into a simulation within Simetar® based upon an empirical distribution. A random number generator was used to select numbers from the empirical distribution. Therefore, the yield numbers used in this research are based upon the empirical distribution of the actual yields recorded by Oklahoma State University. It was found that yields with a minimum of 12 and a maximum of 47.5 tons per acre can be achieved.

Seed

The Kerr Center in Poteau, Oklahoma, did tests on sweet sorghum seed. A plant population of 36,000 seeds per acre was used at the Kerr Center. At $7 per lb. of seed, a 50 lb. bag of seed would cost $350. This would produce a total seed cost of $21 per acre (Kerr, 1985). The sweet sorghum was planted in the month of May. The Kerr Center Budget was assumed to be accurate and was used in this research.

Fertilizer

Fertilizer recommendations include 96 lbs. per acre of nitrogen is used, along with 40 lbs. per acre of both phosphorus and potassium for sweet sorghum (Godsey, 2008). In the production spreadsheet, a fertilizer combination is formulated using anhydrous ammonia, DAP (18-46-0, Nitrogen-Phosphorus-Potassium), and Muriate of Potash (0-0-60). To get the recommended rate of 96 lbs. of nitrogen, 40 lbs. of phosphorus, and 40 lbs. of potassium per acre, the combination would consist of 98 lbs. of anhydrous ammonia per acre, 88 lbs. of DAP per acre, and 66 lbs. of Muriate of Potash per acre. Prices were used from the USDA website for April of 2008 (USDA, 2008). Prices per ton

were: $755 for anhydrous ammonia, $850 per ton for DAP, and $561 per ton for potash. A $3.72 per acre application rate per acre for the DAP and potash is added in the field work section of the production spreadsheet, as well as a charge to apply the anhydrous ammonia of $8.29 per acre.

Harvester

The harvester costs that were assumed in this research come from The University of Minnesota cost estimates for a forage harvester (Lazarus and Selley, 2005). The costs for a forage harvester to cut sweet sorghum are assumed to be the same as the costs for cutting any crop with a forage harvester. The forage harvester would chop the sweet sorghum into small pieces (billets, 1-2 square inches) that could be easily pressed with a screw press at a later time. A cost of $43.58 per acre was estimated in 2005 to have a field custom cut with a forage harvester.

The 2005 study from The University of Minnesota also covered some costs for operating a 570 horsepower self-propelled forage harvester. The base price of this machine was $202.600, it has 200 hours of annual use, and the fuel/oil cost per hour was $34.61. Next, maintenance and repair cost per hour was $15.35 with depreciation cost per hour at $58.97. Overhead cost estimates for this unit were $48.00 per hour ($9,600 per year) and the total cost per hour of use was $156.94 ($31,387 per year.) Finally, this machine drinks 13.68 gallons of diesel per hour (Lazarus and Selley, 2005).

Machinery Operations (Field Work)

All of the field work is assumed to be hired as custom work. Oklahoma State University (Doye, et al., 2006) has custom rates available which can be entered into the spreadsheet. These rates come from the years of 2005-2006 and are in report CR-205. State averages were used.

February

Table IV-2 starts in the month of February. Field work must take place to get the soil ready for the upcoming growing season. Therefore, the conventional tillage operations of chiseling and tandem disking take place. Chiseling will take care of deep soil tillage, ripping deep into the ground to loosen the soil. Tandem disking will bury the residue from the previous crop.

March

The field work in March will be minimal, only the application of fertilizer is to be accomplished. The fertilizer used in the research is Anhydrous Ammonia. The application of Anhydrous Ammonia will place nitrogen within the soil to help the sweet sorghum seed grow when it is planted. Also, the DAP and Muriate of Potash are spread in this March.

April

The final step in seedbed preparation takes place in April. A field cultivator is pulled across the soil to create a perfect seedbed for the sweet sorghum plant. The field

cultivator will bury the remaining residue, remove any weeds, incorporate the nitrogen into the soil, as well as smooth out the soil for planting.

May

Planting finally takes place in the month of May. While the seed could be planted earlier (April), May was the month used in this research. This gives the soil more time to warm and spreads out the spring tillage over more months.

Table IV-2. Schedule of Field Operations for Sweet Sorghum Production in Oklahoma

Month	February	March	April	May	June or July	August - November
Operations	Tandem Disk/Chisel	Fertilizer Application	Field Cultivator	Planter	Cultivator	Harvest
Cost per Acre	$18.17	$12.01	$6.73	$10.60	$6.33	$43.58

June or July

The only remaining field work left to be done before harvest will be to cultivate the fields. This is done either in June or July. Cultivating will remove the fields of weeds. This will help the young plants to grow better, since there will be less competition for space, sunlight, and the nitrogen in the soil. Cultivating will also create a cleaner crop that is free of weeds to make harvesting the sweet sorghum easier.

Land Rental

In this research, it is assumed that non-irrigated (dry-land) land is rented to produce the sweet sorghum. Since sweet sorghum is a hardy and drought resistant crop, it can survive without irrigation. Data had been collected by Oklahoma State University in 2004-2005 on the price of renting dry-land ground (Doye and Sahs, 2005). The state average for renting dry-land ground to raise wheat on, which is assumed to be comparable to ground to grow sweet sorghum on, costs $30.21 per acre to rent.

Final Budget

The final budget is comprised of all of the topics discussed above. The budget is broken down into per acre costs. Land rental costs are $30.21 per acre, custom work costs are $53.84 per acre, seed costs are $21 per acre, fertilizer costs are $92.91 per acre, and custom harvest costs are $43.58 per acre. The total cost can be divided by the yield to calculate a break-even price, which would be the minimal price that could be accepted per ton of sweet sorghum billets to cover the costs of producing the billets.

Table IV-3. Key Assumptions for Sweet Sorghum Processing into Ethanol and Silage.

Variable	Value	Source
Trucking	$4.50 per loaded mile	Garret Long, Gavilon
Federal Tax Credit	$.10 per gallon of ethanol	68 Oklahoma Statute § 2357.66
Oklahoma Tax Credit	$.20 per gallon of ethanol	26 United States Code § 40 (b)(4)
Billets ($/ton)	Variable - Simulated	Spreadsheet 1
Silage	$30 per ton	Bob Kropp, Personal Communication
Ethanol Price ($/gal)	$2.50	DTN Ethanol Center
Natural Gas ($/1000 cubic feet)	$10.52	Energy Information Administration
Wastewater Treatment Costs ($/1000 gallons)	$1.89	City of Stillwater, Utility Services
Fuel Bladder Price (10,000 Gallons)	$11,400	Interstate Products Inc.
Fuel Bladder Price (50,000 Gallons)	$18,900	Interstate Products Inc.
Distillation Unit Costs	$200,000	Anuradha Mukmerjee, Personal Communication
Distillation Inflow Rate	1000 gallons/hour	Variable
Screw Press Costs	$120,000	Clint Cosgrove, Personal Communication
Screw Press Capacity	10 tons/hour	Clint Cosgrove, Personal Communication
Juice Extraction Rate	.55	Dani Bellmer, Personal Communication
Sugar Content	.15	Dani Bellmer, Personal Communication
Fermentation Efficiency	.85	Dani Bellmer, Personal Communication
Irrigation Component Costs	$39,950	Kansas State University MF-836
Yeast Costs	$.0043 per ethanol gallon	U.S.D.A.

Spreadsheet 2: Processing of Sweet Sorghum Billets from Pressing to Delivery

In the Processing Spreadsheet, an outline of expenses and revenues were calculated based upon variables that were assumed to be true. Once again, these assumptions are backed by published research findings, communications with professors, and data collected from recent studies.

There are many more variables in Spreadsheet 2 that can be inputted by the operator such as the percent of the project to be financed and the wage inflation rate. Table IV-3 shows the key variables that will have the most impact on the calculated output.

Input Value

As stated above, there are several inputs that are made and can be changed to alter the calculated outputs. The Input Value sheet covers many of the basic variables, including variables that affect capital structure of the investment, tax information, payroll information, transportation for the input materials and output materials, utility costs, working capital needed, tax credits (subsidies), working parameters, input costs, output prices, and inflation rates.

For this research, the project is 50% financed from the bank, with a 7.5% interest rate used over a 10 year loan rate. The transportation includes the hauling of the billets from the forage harvester in the field to the processing location. The truck that hauls the billets is a semi that runs alongside the forage harvester and has high walls so that the forage harvester can throw the sweet sorghum directly into the truck.

Processing Calculations

The next sheet that has input variables is the Processing Calculations page. Variables on this page include acreage, yield, juice extraction rate, sugar content, pounds of ethanol per pound of sugar, and fermentation efficiency. The yield is inputted directly from Spreadsheet 1. The Processing Calculations sheet takes a set number of tons of sweet sorghum billets (produced from acreage multiplied times simulated yield from Production Spreadsheet) and calculates the number of gallons of ethanol that can be expected based upon the other variable inputs and set numbers from research. The numbers that are set from research include pounds of ethanol per pound of sugar (.51), the density of the sweet sorghum juice (8 pounds per gallon), and the density of ethanol (6.58 pounds per gallon) (Bellmer, 2008). The Processing Calculations sheet also calculates the amount of silage that will be a byproduct to be used for cattle feed.

Utilities

There are more variables that can be inputted on the Utilities sheet. The first two variables set the cost of distillation. These variables are input gallons per hour of juice to be distilled and the second one is distiller efficiency. The next variable is the chemicals and materials. This variable is expressed in dollars per year and is not expected to be a major expense. It was inserted to cover the cost of yeast for fermentation.

The next variable on the Utilities sheet is the cost of disposing of the wastewater. This can be done two different ways. First, the water can be run through a municipal wastewater system. A variable is inputted on the Input Sheet to calculate this cost. This variable is in dollars per 1000 gallons and is the cost of cleaning the sewage wastewater.

The second way to dispose of wastewater is to irrigate it onto a field. When this option is selected, it activates irrigation equipment which is already located in the equipment page, which will increase the capital investment cost of the processing. The equipment necessary to irrigate the wastewater (pump, gear-head, power unit, and 8” underground pipe) costs $39,950 (Dumler, et al., 2007). The variable cost of irrigating the wastewater onto the field is calculated dependent on the natural gas cost.

The other utility costs are derived from numbers that are imported from the Input Value, Equipment, and Processing Calculations sheets. The final output from the Utilities sheet is the total yearly cost of the utilities used in the on-farm processing of sweet sorghum for ethanol.

Equipment

All of the necessary machinery for processing sweet sorghum is entered into the Equipment sheet. This includes the screw press, storage bladders, the distillation unit, and the irrigation equipment (only added if irrigation option is selected in utilities sheet). The Equipment page does not include any buildings or vehicles. Also on this sheet is a description of the equipment, the estimated price, and the units and value of energy that the piece of equipment uses.

Personnel Expenses

The next sheet that has adjustable variables is the Personnel Expenses page. The variables that are entered here include the employee position, the price (salary for administrative positions and hourly for production positions), and the percentage of overtime that the employees will be working. The number of hours that is worked by the

hourly workers is determined by their position. The employee who runs the screw press will be employed as many hours as it takes to press all of the sweet sorghum billets. The employee who is in charge of running the distillation unit works as many hours as it takes to distill all of the fermented juice. The administrative position was set at $50,000 yearly and the hourly positions receive $12 per hour of work.

Depreciation

The Depreciation sheet takes care of calculating the depreciation expense on a yearly basis. There are four types of depreciable assets including: buildings, special purpose buildings, equipment and heavy rolling stock, and light trucks and vehicles. Buildings are depreciated on a 39 year straight line. Special purpose buildings are depreciated on a 10 year straight line. Equipment and heavy rolling stock (from Equipment sheet) is depreciated on a 7 year MACRS with a half year convention. Finally, the light trucks and vehicles are depreciated on a 5 year MACRS with a half year convention. In the light trucks and vehicles section, a loader tractor (valued at $30,000) is inserted to be used for handling the billets before processing and the silage after processing.

Registration Requirements

There are additional costs that come with the registration of the production facility as well as the ethanol itself. Many of the laws set up by the Environmental Protection Agency (EPA) were set up for larger scale ethanol facilities (around 40 million gallons of ethanol per year). There is a grey area as to whether a smaller on-farm ethanol production facility and the ethanol produced must register with the EPA. To solve this problem and

avoid trouble, the producer can apply for an applicability determination through the EPA. Since there are no clear-cut answers for the registration of smaller scale ethanol production, the EPA will let the producer know what is necessary to be a legal facility (Ferrell, 2008).

The OAC §§ 252:100-7-1.1, 252:100-7-2 deals with air permitting issues. Since there has not been research to test the air emissions from the on-farm production of ethanol from sweet sorghum, there is know way to know what permits may be required. It is likely though that the producer will not need any more then a Minor Source Permit, if even that. Further research must be completed to test the air emissions.

As stated in the literature review, there are a few ways to distribute the waste water, including treating the water in the local municipal waste water treatment system or land applying the waste. The un-permitted discharge of any pollutant to most bodies of water is prohibited both by the Clean Water Act (33 U.S.C. §§ 1251) and the Oklahoma Pollutant Discharge Elimination System Act (27A Okla. Stat. §§ 2-6-201). In the Processing Spreadsheet, the waste water is run through the local municipal waste water treatment program at a cost of $3.75 per 1000 gallons treated.

The Oklahoma Corporation Commission (OCC) has jurisdiction over a variety of storage tank facilities for petroleum-based fuels and associated substances. Since ethanol is not petroleum-based, the OCC does not worry about storage tank registration for ethanol 40 C.F.R. § 112.1(d).

The majority of the cost for complying with regulations is going to come with the distillation facility registration. Since the producer is creating alcohol, they must register

with the U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) (26 United States Code § 5181).

Table IV-4. Distillation Facility Registration Bond Requirements (26 U.S.C. § 5181 (c)(3),(4).

Minimum gallons	Maximum Gallons	Bond Price
5,025	10,050	$2,000
10,050	15,075	$3,000
45,226	50,251	$10,000
95,477	100,503	$20,000
246,231	251,256	$50,000

(Ferrell, 2008)

An operations bond is required for medium and large ethanol producers. The ethanol producer may pledge securities which are transferable and are guaranteed as to both interest and principal by the United States (§19.955 Bonds) (Ferrell, 2008). Examples are shown in Table IV-4

Beyond posting the given bond price, the producer must pay a special occupational tax. For the national tax the rate is $500 per year (C.F.R. §§ 19.50). On a state level, the Oklahoma Department of Agriculture, Food and Forestry (ODAFF) enforces a tax rate of $100 on producers OAC §35:13-1-2, 35:13-1-5 (Ferrell, 2008).

The incentive for compliance with the regulations is the tax credits that get paid per gallon of ethanol production. At the federal level, the tax credit of greatest interest to the ethanol producer is the Small Ethanol Producer Tax Credit. For producers of 60 million gallons of ethanol or less per year, a credit of $.10 per gallon is awarded. A producer can receive a maximum of $1.5 million per year from the Small Ethanol

Producer Tax Credit 26 (U.S.C. § 40(b) (4)). The state level in Oklahoma allows for a $.20 per gallon tax credit (Okla. Stat. § 2357.66) to any facility operating at 25% or more of its original design capacity in terms of ethanol produced per year (Ferrell, 2008).

The ethanol produced from the process used in this research is non-denatured, but in order for an on-farm producer of ethanol to qualify for treatment as a fuel alcohol facility to obtain the benefit of the fuel alcohol exemption from alcohol excise taxes, the producer must follow the ATF's denaturant requirements. The point in denaturing the ethanol is to make it unsuitable to drink as a beverage 26 U.S.C. § 5242. Denaturing is accomplished by combining ethanol with an approved "denaturant" such as gasoline, kerosene, deodorized kerosene, rubber hydrocarbon solvent, methyl isobutyl ketone, heptane, or any combination of these denaturants. If the fuel alcohol (ethanol) is to be used in an engine that is subject to EPA automotive regulations, then EPA-approved gasoline must be used as the denaturant 27 C.F.R. § 19.1005(c)(1)(i). In the case of ethanol to be sold for fuel for cars, gasoline would be the denaturant of choice due to its availability, price, and regulatory environment. The gasoline must be applied in the ratio of 2 gallons per 100 gallons of ethanol 27 C.F.R. § 19.1005(c).

Processing Simulations

Five simulations were run to test the feasibility of on-farm production of ethanol from sweet sorghum in Oklahoma. There were four variables that were changed to test against a baseline simulation. The base simulation is on 500 acres, includes a silage value of $30 per ton, has the wastewater disposed of through the municipal system, and has a sugar content of 15%. The second simulation changes the acreage to 160 acres. 160 acres was used to represent a smaller farm on a quarter section piece of ground. The main

importance of the farm size is the capability to take advantage of the economies of scale. The larger farm (500 acres) will have more gallons of ethanol to spread the fixed costs over, thus lowering their costs per gallon. The third simulation sets the silage value at $10 per ton. This is used to test the feasibility if the producer cannot get $30 per ton for their silage. The fourth simulation differs from the baseline only by the fact that it disposes of the water through the irrigation system. This increases the investment costs but lowers the yearly utility costs. The final simulation changes the sugar content from 15% in the base to 19%. The sugar content used in the base is seen as conservative and the value used in the final simulation is viewed as the upper range for the sugar content variable.

In all five simulations, the transportation mileage for the sorghum billets and the silage are set low to represent a close proximity between the fields where the crop is grown, the processing facility, and the location where the silage is fed to cattle. The ethanol shipping distance is set at 100 miles. The screw press capacity (120 tons per hour) and the distillation capacity (1000 gallons per hour inflow rate) comes from a processing system designed by the Oklahoma State University Department of Chemical Engineering (Whiteley, 2008) (Mukherjee, 2008) and Sulzer ChemTech, USA. The processing calculations (juice extraction rate, sugar content, and fermentation efficiency) come from lab test run at Oklahoma State University. Values calculated in the production spreadsheet (yield, break-even price) were used in the processing simulations to depict an accurate scenario.

CHAPTER V

RESULTS

The simulation process was broken down into two sections. The production simulation calculates the break-even price of a ton of sweet sorghum based upon production costs and yields. The production costs parameters are listed in the production budget. Results from the simulation in the production spreadsheet are listed in Table V-1. These values are used later in the processing simulations.

Table V-1. Simulation Results from Spreadsheet 1 : Sweet Sorghum Production Budget

Variable	Average	Standard Deviation	Minimum	Maximum
Yield (tons/acre)	24.90	8.15	12.01	47.42
Break-Even Price ($/ton)	$10.72	$3.36	$5.09	$20.10

Five simulations were run to test the feasibility of on-farm production of ethanol from sweet sorghum in Oklahoma. As stated earlier, there were four variables that were changed to test against a baseline simulation. The base simulation is on 500 acres, includes a silage value of $30, has the wastewater disposed of through the municipal system, and has a sugar content of 15%. The second simulation changes the acreage to 160 acres. The third simulation sets the silage value at $10 per ton. The fourth simulation differs from the baseline only by the fact that it disposes of the water through the

irrigation system. The final simulation changes the sugar content from 15% in the base to 19%. The results for the 500 acre base simulation are shown in Table V-2

Table V-2. 500 Acre Sweet Sorghum Processing Simulation Results, Base.

Variable	Average Value (Standard Deviation)
Acres	500
Yield (tons/acre)	24.90 (8.15)
Net Present Value (over 10 years, 10% discount rate)	$2,714,867 ($2,440,667)
Ethanol Production (gallons)	135376 (44,273)
Break Even Price ($/ton)	$10.72 ($3.36)
Silage Value ($/ton)	$30
Screw Press Days	103.78 (33.94)
Distiller Inflow Rate (gallons/hour)	1000
Distillation Days	71.35 (23.33)
Distance Sorghum Billets (miles)	1
Distance Ethanol (miles)	100
Distance Silage (miles)	15
Juice Extraction Rate (%)	55
Sugar Content (%)	15
Fermentation Efficiency (%)	85
Yearly Utilities ($)	$29,195 ($9,547)

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The maximum net present value in the base processing simulation was $9,460,983 whereas the minimum was -$1,147,548. This would be a 133% Internal

Rate of Return and a negative Internal Rate of Return respectively. The mean Internal Rate of Return on the base simulation was 47%. All Net Present Values in the simulations are based upon a 10 year time frame and have a discount rate of 10%. The maximum and minimum yields and break-even prices were the same as in the production simulations, and are the same throughout the processing simulations. The screw press days were always greater than the number of days the distiller had to run meaning that the distiller could always keep up with all of the sweet sorghum that the screw-press could process. Yearly utilities ranged from $55,585 per year to $14,086 in the base simulation.

The second processing simulation was run for a smaller operation that only has 160 acres of sweet sorghum produced per year. The other values remain the same in this simulation, including the equipment size. Results from this simulation are shown in Table V- 3.

Net Present Value in the second processing simulation ranges from $1,181,870 to a negative $2,212,860. Again this is based upon a 10 year time frame with a discount rate of 10%. The yield and break-even price have the same range as they did in the first simulation. Screw press days decreased and had a range of 32 to 10 days. Distillation days also decreased and had a range of 22 to 8 days. Again, the distiller works faster than the press does. In the smaller simulation the utilities went from a yearly maximum of $17,788 to a minimum of $4,509.

Table V-3. 160 Acre Sweet Sorghum Processing Simulation Results.

Variable	Average Value (Standard Deviation)
Acres	160
Yield (tons/acre)	24.90 (8.15)
Net Present Value (over 10 years, 10% discount rate)	($976,887) ($781,013)
Ethanol Production (gallons)	43,320 (14,167)
Break Even Price ($/ton)	$10.72 ($3.36)
Silage Value ($/ton)	$30
Screw Press Days	33.20 (10.86)
Distiller Inflow Rate (gallons/hour)	1000
Distillation Days	22.83 (7.46)
Distance Sorghum Billets (miles)	1
Distance Ethanol (miles)	100
Distance Silage (miles)	15
Juice Extraction Rate (%)	55
Sugar Content (%)	15
Fermentation Efficiency (%)	85
Yearly Utilities ($)	$9,343 ($3,055)

The third simulation again used 500 acres, but this time the silage value is set to $10. This is used to simulate a downturn in the demand for silage as cattle feed. The results are shown in Table V-4.

Table V-4. Sweet Sorghum Processing Simulation Results assuming $10 Silage

Variable	Average Value (Standard Deviation)
Acres	500
Yield (tons/acre)	24.90 (8.15)
Net Present Value (over 10 years, 10% discount rate)	$827,246 ($1,823,344)
Ethanol Production (gallons)	135,376 (44,273)
Break Even Price ($/ton)	$10.72 ($3.36)
Silage Value ($/ton)	$10
Screw Press Days	103.78 (33.94)
Distiller Inflow Rate (gallons/hour)	1000
Distillation Days	71.34 (23.33)
Distance Sorghum Billets (miles)	1
Distance Ethanol (miles)	100
Distance Silage (miles)	15
Juice Extraction Rate (%)	55
Sugar Content (%)	15
Fermentation Efficiency (%)	85
Yearly Utilities ($)	$29,195 ($9,547)

The Net Present Value ranges from $5,867,054 to negative $2,058,241 for the third simulation. The production numbers (ethanol production, press days, distillation days, and yearly utilities) are all the same as the first simulation, only the Net Present Value changes.

The fourth simulation uses the same variables as the base except it disposes of the wastewater through an irrigation system. When the irrigation system is used, the capital

costs increase (due to buying irrigation pipe, a pump and wellhead, and a power unit) but the variable yearly utility costs decrease. The results are shown in Table V-5

Table V-5. Sweet Sorghum Processing Simulation Results Assuming Irrigation Wastewater Disposal

Variable	Average Value (Standard Deviation)
Acres	500
Yield (tons/acre)	24.90 (8.15)
Net Present Value (over 10 years, 10% discount rate)	$2,612,025 ($2,449,794)
Ethanol Production (gallons)	135,376 (44,273)
Break Even Price ($/ton)	$10.72 ($3.36)
Silage Value ($/ton)	$30
Screw Press Days	103.78 (33.94)
Distiller Inflow Rate (gallons/hour)	1000
Distillation Days	71.34 (23.33)
Distance Sorghum Billets (miles)	1
Distance Ethanol (miles)	100
Distance Silage (miles)	15
Juice Extraction Rate (%)	55
Sugar Content (%)	15
Fermentation Efficiency (%)	85
Yearly Utilities ($)	$27,538 ($9,005)

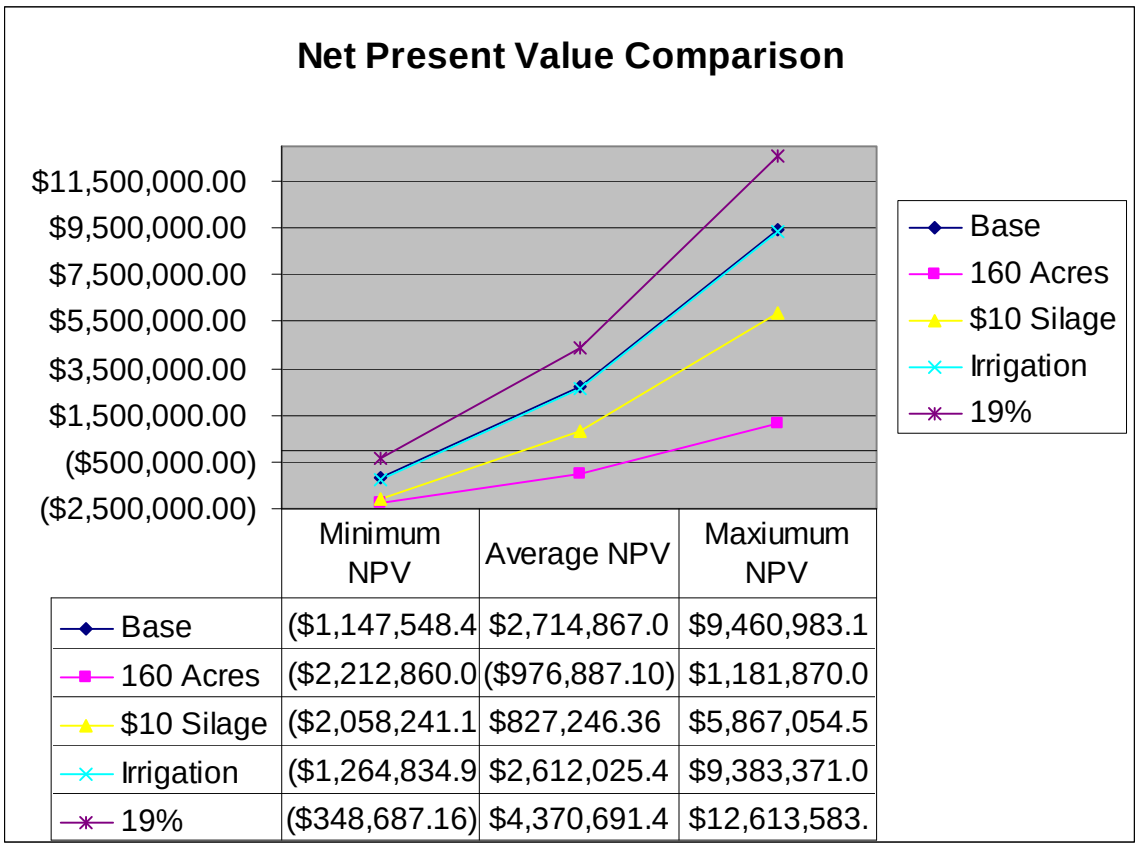
The fourth simulation has a slightly lower Net Present Value than the base simulation. The Net Present Value ranges from $9,383,371 to a negative $1,264,834.

Table V-6. Sweet Sorghum Processing Simulation Results Assuming 19% Sugar Content

Variable	Average Value (Standard Deviation)
Acres	500
Yield (tons/acre)	24.70 (8.14)
Net Present Value (over 10 years, 10% discount rate)	$4,370,691 ($2,982,183)
Ethanol Production (gallons)	171,476 (56,079)
Break Even Price ($/ton)	$10.72 ($3.36)
Silage Value ($/ton)	$30
Screw Press Days	103.78 (33.94)
Distiller Inflow Rate (gallons/hour)	1000
Distillation Days	71.34 (23.33)
Distance Sorghum Billets (miles)	1
Distance Ethanol (miles)	100
Distance Silage (miles)	15
Juice Extraction Rate (%)	55
Sugar Content (%)	19
Fermentation Efficiency (%)	85
Yearly Utilities ($)	$29,127 ($9,525)

The final simulation changes the sugar content to 19%.. This number was set low (15%) in the base simulation to show a cautious Net Present Value. Results from this simulation are shown in Table V-6.

The Net Present Values increase to their greatest value with the increase in sugar content. This is due to the fact that there is more ethanol to spread the average fixed costs over. While the utilities also increase, the return from processing is greater then the added costs so the overall Net Present Value increases.



	Minimum NPV	Average NPV	Maxiumum NPV
Base	($1,147,548.4	$2,714,867.0	$9,460,983.1
160 Acres	($2,212,860.0	($976,887.10)	$1,181,870.0
$10 Silage	($2,058,241.1	$827,246.36	$5,867,054.5
Irrigation	($1,264,834.9	$2,612,025.4	$9,383,371.0
19%	($348,687.16)	$4,370,691.4	$12,613,583.

Figure V-1. Net Present Value Comparison.

Figure V 1 is a comparison of the five simulations and their respective Net Present Values. The final simulation with a 19% sugar content clearly has the highest Net Present Values. This simulation is followed by the base simulation, then the simulation in which an irrigation system is used to dispose of the wastewater, next is the simulation with the $10 silage value, with the simulation on 160 acres returning the lowest Net Present Values.

CHAPTER VI

CONCLUSIONS

Sweet sorghum is a potential alternative feedstock to produce ethanol. The objective of this research was to determine the economic feasibility of growing sweet sorghum for small-scale, on-farm production of ethanol in Oklahoma. Sweet sorghum would work well as a renewable energy crop in Oklahoma for several reasons. First, it fits in a crop rotation with several crops grown in Oklahoma such as wheat, soybeans, and cotton. The climate and soil types of Oklahoma are adequate so that sweet sorghum can flourish. The equipment requirements are similar for sweet sorghum and other Oklahoma grown crops. Next, sweet sorghum has a long harvest window that can fit around other farm jobs for other crops or livestock production. Then, the byproduct of this process, silage, can be used as a cattle feed. Finally, sweet sorghum is a low input producer of carbohydrates that can be converted into large amounts of ethanol per acre.

The main disadvantage to producing ethanol from sweet sorghum is the issue of storability of sweet sorghum billets and the unfermented juice. Corn or grain sorghum can be stored until the ethanol plant is prepared to process the grain. With sweet sorghum, the billets must be pressed and fermentation needs to be started within 24 hours of harvesting. After fermentation has taken place, the juice is in a stable state, and after distillation has take place, the ethanol is also in a stable state.

The results, based upon hypothetical assumptions, conclude many facts about producing sweet sorghum for the on-farm production of ethanol in Oklahoma. First, the greater the number of acres of sweet sorghum grown, the higher the Net Present Value will be. This was shown with the simulation on the 160 acre farm, which had a smaller Net Present Value as opposed to the 500 acre farm. Next, the results show that a decrease in the price of silage has a major impact on the feasibility of producing ethanol from sweet sorghum. In the simulations, when the byproduct silage was worth one third ($10) of the base price ($30), the average Net Present Value decreased by $1,877,620. Third, it was shown that using a municipal wastewater system produces a higher Net Present Value than purchasing the equipment and using an irrigation system at the prices used in the simulation. This is due to the lower initial investment costs of the municipal system. Finally, the results proved that higher sugar content will increase the Net Present Value. This is because there is more ethanol produced per acre at the same production and processing costs when a higher juice extraction rate and sugar content are present.

There is potential as well as limitations for the process of creating ethanol on-farm in Oklahoma that was used specifically in this research. To start, a farmer has potential to increase their returns per acre. For farmers with a smaller number of acres, producing on-farm ethanol could provide an opportunity to reap a larger income. This process also has the potential to provide fuel for the state and to lower energy costs. One limitation of this process is the large initial investment that is required. Since all of the production work can be done by custom operations, there is no large capital investment into producing the sweet sorghum. The large investment comes with the processing equipment, namely the storage bladders, the screw press, and the distillation unit. One

potential solution for this problem would be to share these large investments with a neighboring farmer or farmers as a cooperative venture. The member of the cooperative could jointly invest in larger equipment that could decrease expenses. The regulations and policies that are placed on ethanol production could be one other potential limitation for the Sorganol™ process. Since there are not many statutes dealing with such a small scale ethanol production facility, there are many unknown legal costs that may affect the profitability of the facility.

There are several assumptions that could change the profitability of the system. First, nitrogen prices are increasing at a rapid rate, and could become an even bigger concern in the cost in the overall process. Next, gasoline, natural gas, electricity, and ethanol prices are also changing (increasing) at a rapid rate. These rapid changes could help (increased ethanol value) or hurt (increased production and processing costs) the feasibility of on-farm ethanol production from sweet sorghum. The next assumption that could affect the profitability is the price and inflow rate of the distillation system. Only after a distiller has been manufactured and in use for a while will the costs be known. Another assumption that could potentially hurt the profitability of the on-farm process is the amount of labor that is necessary to produce the ethanol. It may take more or less labor then was used in the simulations depending on how labor intense the screw press and distillation unit are. Marketing such a small amount of ethanol (compared to larger, 40 million gallon per year, corn-based facilities) could be difficult. It would be a risk for blenders (who mix ethanol with gasoline) to accept ethanol from farmers since their products could be inconsistent between batches or compared to other farmers. A cooperative venture for marketing this ethanol could be the solution for this problem.

Since there are no corn-based ethanol plants in Oklahoma, producing ethanol from sweet sorghum is a way for the state to enter the renewable energy market without the investor's great expense of a corn-based facility. This would provide another marketable commodity for the state and could potentially lower energy costs within the state.

There were three hypotheses made in the methods section of this paper. In conclusion, this research has shown that the break-even price does not always decrease with an increasing yield. The overall production cost (mainly the nitrogen cost and amount applied) have a major affect on the break-even price. Next, the processing costs per gallon do increase with any increase in the processing costs (increased natural gas costs, increased trucking rates, increased labor rates, etc.). Finally, this research has shown that any law or regulation that increases the costs of production will negatively impact the feasibility of growing sweet sorghum for the on-farm production of ethanol in Oklahoma.

CHAPTER VII

RECOMMENDATIONS

Producing ethanol on-farm from sweet sorghum in Oklahoma appears to have potential. As for any project, the availability of consistent, reliable data increases the probability of accurately projecting economic feasibility. While there has been close attention paid to collecting accurate field test data from the research stations around the state, more data covering different production conditions over multiple time periods can only improve the accuracy of this project. Recording this field test information will provide more robust empirical distributions for stochastic analyses. Production variables that should be considered in future research include:

- Moisture (rainfall, irrigation)
- Soil type (pH, organic matter)
- Fertilization (lbs/a N, lbs/a P_2O_5, lbs/a K_2O)
- Dates (planting, harvesting, moisture, fertilization)
- Growing conditions
- Harvesting/handling methods
- Variety
- Yield (tons/acre, sugar content, juice expression, ethanol potential)

This data needs to be obtained at the various test stations throughout the state. By having the crop grown throughout the state, it can be shown how sweet sorghum will adjust and produce in the differing characteristics (rainfall, soil types, etc.) of these different test station locations. More reliable information can be obtained about the production of sweet sorghum if it is grown on more acres at these test stations. Larger acreage plots will provide more dependable data by making the test plot closer to a true-farm situation.

Next, the data on the test plots needs to take place over many years so that sweet sorghum can show its ability to produce in varying growing conditions. More years of production data will provide more accurate research results. The test plots can show the effects of using sweet sorghum in a crop rotation or the effects of planting sweet sorghum after sweet sorghum on the same land. Will not having any residue from last years sweet sorghum crop (it is turned into silage) affect the yield of this years crop? How well would a rotation work with Oklahoma's major crop, wheat?

Finally, the effects of dry land versus irrigated sweet sorghum need to be tested. It is assumed that irrigated crops will yield more, but will this increase in yield outweigh the costs of irrigating? Will this only add more moisture to the crop that will have to be pressed and distilled later, increasing processing costs? What about if the crop is irrigated with the wastewater from the distillation of the previous years sweet sorghum crop? Does this waste water possess any nutritive value, or is irrigating it on just a way to dispose of the waste?

The collection of this information will bolster producer confidence in feedstock production capabilities and could entice seed companies to take an interest in developing

varieties specifically for biofuel feedstock. It is worth noting again, the information collected so far has been valuable, but the more data means increased accuracy of findings in future studies.

There are many issues that need to be researched with respect to the harvesting of sweet sorghum. In this research, a simple forage harvester is used for 4 reasons: they are relatively cheap, they are commonly used in Oklahoma, their product can be processed in a screw press, and their product (after pressing) can be used for cattle feed without further processing. There are many other options that need to be explored for harvesting. Lee McClune's prototype is supposed to harvest the crop and press the stalks in the field. This would leave residue on the field for next year's crop plus it would not require the producer to buy a stationary press. The efficiency of this roller press needs to be tested. McClune's system would not provide any silage for cattle feed and would require different logistics with a truck collecting juice from the harvester in the field to take to the storage bladders. Sugarcane harvesters can harvest the crop and chop it into 1 foot billets, which would be able to pull through a roller press. This would provide for an alternative type of press, but again would not readily provide cattle feed. Also, these sugar cane harvesters worked at slow speeds (Salassi and Deliberto, 2008). Finally, many systems were tested in the Piedmont, which are worth retesting for their efficiency (Rains and Cundiff, 1993). All of these systems should be compared to one another at the tests stations in Oklahoma.

The byproduct, bagasse silage, can be used for many processes. In this research it was used for cattle feed. It can also be used to burn as fuel that could produce power to run the distillation unit or sell on a grid (Gnansounou, et al., 2005), it could be researched

as an input for cellulosic ethanol, or it can be left on the field to provide residue for the next year's crop. These options need to be tested to find the most cost efficient option that will provide long-term success to the process of producing on-farm ethanol from sweet sorghum in Oklahoma. Roller presses and a large-scale screw press need to be tested as well to find which is more efficient. The type of bagasse produced depends on the type of press used, and the output values of the bagasse may determine which type of press is preferred.

Fermentation is also a key variable in the success of this project. There are many questions that need to be researched with respect to fermentation. What is the process for starting fermentation? What temperature range can fermentation take place over? What additional chemicals need to be added to the juice to make fermentation take place? What is the most flexible strain of yeast to use for the bulk fermentation of sweet sorghum juice? Can farmers maintain their own strains of yeast? Is 85% really a close estimate of how efficient fermentation can be at a large-scale? What could be done to increase the fermentation efficiency? The storage bladders need to be tested as well. How will this scale of fermentation affect the efficiency of fermentation? Will the storage bladders really last for 10 years outside and how long would they last if they were stored inside? What kind of effort will it take to clean these large storage bladders and prepare them for storage? All of these questions need to be tested in a lab and then the results again tested in full-scale situations.

As previously stated, the distillation cost is a huge variable in the overall feasibility of this project. As this thesis is being written, Oklahoma State University is working to get a representative small-scale distillation unit built for the purpose of

making production runs using sweet sorghum juice collected from field trials and fermented in small-scale containers. This unit would ultimately be the size that would fit most on-farm operations. After this unit is built and in place, more accurate information will be available about the costs of the unit, the operating costs of running the distiller, and the personnel requirements for running the unit (can a farmer run the machine).

The next recommendation would be to work on the formation of a cooperative for the production and marketing of ethanol produced from sweet sorghum in Oklahoma. A producer-owned cooperative would address several issues related to production, harvesting, and processing of sweet sorghum. First, farmers in the cooperative could pool their money together to get larger equipment, which would be more efficient (and cheaper) than having several sets of smaller equipment. Since sweet sorghum has a large harvest window, from August to November, the use of this equipment could be scheduled so that the equipment would always be in use throughout the harvest window. The crop could be planted with different dates or varieties so that the crop could be harvested when it had the peak moisture (within this harvest window) at the specific time that the farmer gets to use the equipment. The only problem is that it is impossible to be able to predict exact harvest dates when the crop is being planted. With more research these dates could become more accurate. Finally, it would allow for a market for the producers (farmers) and consumers (gasoline blenders, cattle feeders) to trade in.

The final recommendation would be to actually develop and closely monitor the operations of a scaled-up pilot plant for ethanol production from sweet sorghum. Simulations can be very valuable, but the only way to test the simulations results is to create a real-life situation in which to test the process. As of now, Oklahoma State

University possesses the small scale equipment necessary to complete the process from planting the sweet sorghum crop through fermentation of the juice (this equipment is not the exact same as that used in the research, but it does the same job). The final step in process, distillation, is still the major unknown variable. With the bio-energy lab that Oklahoma State University is building (which will hopefully include a distiller), this testing will become possible.

There are many opportunities for future research that were discussed in this section. While the two templates are a start on researching the feasibility of producing ethanol on-farm from sweet sorghum in Oklahoma, there is much research that can still be conducted. Many of the variable can that were inserted into the template need to be further researched and updated in the templates after more accurate information is found.

APPENDIX

Table VIII-1. Sensitivity Analysis of Returns at Different Sweet Sorghum Yields.

Yield (wet tons/acre)	Net Present Value	Internal Rate of Return
5	($3,249,944)	-
10	($1,751,794)	-
15	($253,644)	(2.09%)
20	$1,244,506	26.20%
25	$2,742,656	47.55%
30	$4,240,806	67.47%
35	$5,738,955	86.94%
40	$7,237,105	106.24%
45	$8,735,255	125.47%
50	$10,233,405	144.67%

Table VIII-2. Sensitivity Analysis of Returns at Different Ethanol Prices.

Ethanol Price	Net Present Value	Internal Rate of Return
$2.00	$1,359,265	27.97%
$2.10	$1,587,190	31.35%
$2.20	$1,815,116	34.65%
$2.30	$2,043,041	37.89%
$2.40	$2,270,967	41.08%
$2.50	$2,498,892	44.23%
$2.60	$2,726,817	47.33%
$2.70	$2,954,743	50.41%
$2.80	$3,182,668	53.47%
$2.90	$3,410,594	56.50%
$3.00	$3,638,519	59.52%
$3.10	$3,866,445	62.52%
$3.20	$4,094,370	65.51%
$3.30	$4,323,296	68.48%
$3.40	$4,550,221	71.45%
$3.50	$4,778,147	74.41%

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VITA

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Major Field: Agricultural Economics

Scope and Method of Study: Technology that would enable use of sweet sorghum for an ethanol feedstock is under development. The demand for ethanol is increasing to reduce the dependence on foreign oil. This study was conducted to determine the cost to grow, harvest, press, ferment, distill, store, and transport ethanol produced on the farm from sweet sorghum in Oklahoma. It uses a feasibility budget to determine these costs. This study also determines how policies that restrict production and processing influence costs.

Findings and Conclusions: Results from the first simulation reveal that increasing the acres of sweet sorghum for ethanol will produce a higher Net Present Value. Results from the second simulation conclude that decreasing the value of the byproduct silage bagasse has a major negative impact on the feasibility of the process. The results from the third simulation show that using a municipal wastewater system to dispose of water produces a slightly higher Net Present Value then using an irrigation system to dispose of the water. Results from the final simulation show that increases to the sugar content of the sweet sorghum have a significant positive impact on the Net Present Value. It was also found that there are many aspects of the overall process of producing sweet sorghum for the on-farm production of ethanol that need to be researched further.

Advisor's Approval _____