

SWEET SORGHUM TO ETHANOL A GUIDANCE MANUAL FOR THE GROWER

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ABSTRACT

Ethanol is an important renewable fuel. It is mainly produced from sugar cane, corn, and milo. The diversion of the grain crops from the food chain to fuel has caused widespread direct increases in prices of corn based foods and indirect increases in prices of beef, pork, and chicken products. A viable replacement crop for corn and sugar cane is sweet sorghum. The juice from this cane crop is used to make molasses. This crop has two advantages over corn, first it does not impact the food chain; and second, juice that is extracted from the cane can be fermented and distilled directly. Sweet sorghum is a relatively low water use crop that is planted in the spring and then harvested 120 to 180 days later, depending on the variety. Over the past 10 years the University of Arizona has been growing various varieties of sweet sorghum with the final goal to increase the harvest season while maintaining juice and sugar yields. The greatest challenge with sorghum is not growing or processing the juice, but extracting the juice economically. The capacity of equipment to process the juice is directly tied to the number of days per year that the crop can be harvested. The highest yielding varieties are long season varieties that are photosensitive, mature when the number of daylight hours in the fall is less than 12.5 hours. These varieties result in a 30 to 45 day harvest/processing window. The short season varieties mature on a heat unit basis. The harvesting and processing season was maximized, over 120 days, with staggered plantings of short season varieties and a planting of a long season variety.

Keywords: Sweet Sorghum; Ethanol; Guidance Manual

INTRODUCTION

The purpose of this paper is to document the viability of Sweet Sorghum as a biofuel crop in Arizona. In order to be a viable crop the follow-ing must be present:

- Climate suitable for growing the crop
- Growing practices conducive to producing optimal yield with minimal inputs with existing knowledge. Farmers will not grow a new crop if they do not have experience with similar crops.
- Ability to harvest and process the crop
- Market for the crop. The immediate market is the ethanol plant. The secondary market is the regional demand for the finished product – ethanol.

The ultimate goal of every farmer, processor, and jobber is to earn a living, so economics is always a consideration. The University of Arizona has been researching this crop since 2006, so they have demonstrated that the crop can be grown, and the inputs (farming practices, water, and fertilizer needs) are known. The crop is grown similar to grain sorghum and forage crops, which are known to every farmer in the region. This paper will explore the division point between the farmer and processing plant, and recommendations of where to draw the line will be made, based on economics of the process. In order to help draw the line between the farmer and the processor this paper will cover several methods to harvest and extract the juice from the crop.

BACKGROUND

The United States imports approximately 65-percent of the crude oil consumed per year. The oil is refined for various uses in transportation and industry. The transportation sector (gasoline, diesel, and jet fuel) consumes 70-percent of the oil [1]. One possible method to reduce our dependence on foreign oil is through the substitution of biologically based fuels. Proposed fuels include ethanol, which in the United States has chiefly been produced from corn and grain sorghum. Brazil has been successful in moving from fossil fuels to bio-fuels; today 100-percent of cars run on ethanol made from sugar cane.

Many believe that corn ethanol would not exist without Federal subsidies. The subsidies started with tax credits in 1978 and had increased to \$.50 per gallon until they were repealed in 2011. Production increases were not just driven by subsidies, but they also increased as cities and states passed laws requiring ethanol as an additive in gasoline to decrease air pollution. The increase in production of ethanol was driven by the following Federal laws and policies:

- 1990-Clean Air Act was amended to mandate the use of ethanol in 39 major carbon monoxide non-attainment areas in the winter and year-round in 9 severe ozone non-attainment areas.
- 2006-Renewable Fuel Standard Program is signed. It was designed to encourage the blending of ethanol into regular car fuel.
- 2007 – Energy Independence and Security Act required the use of 15 billion gallons of ethanol by 2015.

Most of the ethanol consumed is made from corn. The use of corn resulted in concerns about the amount of arable land required to grow corn and the impact on the grain supply as a food source. The price of corn increased when more than 25% of the crop was diverted to use by the bio-fuel industry. Corn is such an integral ingredient in the growth or production of foods that the higher corn prices caused meat and dairy prices to increase as well as other grain prices because they were used as substitutes for corn. As ethanol use increased the price of corn followed. The price increase in 2008 was the perfect storm of corn to ethanol demand increases and a drought in the mid-west. In 2009 the price stabilized for a few

years. The high demand for corn's use in biofuels caused the corn prices to become tied to fuel prices. In 2010 we experienced large increases in the price of crude oil, Figure 1, and consequently the price of corn followed this trend. This trend has followed the fuel prices down.

Most ethanol plants produce ethanol and wet and dried



Fig.1. Corn Price Trend 2010 – 2015

distiller's grain and solubles (DGS). The DGS is a valuable by-product of the corn to ethanol process because it has a high protein and fat content. Dried distillers grain (DDGS) has to go through another process to dry the product but it can be stored for a longer period of time, so it can be shipped overseas to high value markets.

SWEET SORGHUM

The process to turn sweet sorghum juice into ethanol is much less energy and water intensive than that for corn. The juice is added to the fermentation tank with yeast, and the beer is produced. No additional water is needed. The fermented juice, beer, is then distilled and dewatered; a simple two-step process that takes just over two days.

The basic goals in growing sweet sorghum are to minimize production cost and inputs. This is done through:

Use of poor quality water sources; the salinity of the irrigation water can approach 8dS/m without impacting yield [2]. The water can be well, river, or reclaimed water. Also, the crop takes advantage of monsoon moisture.

Grow on poor quality soils; well suited for saline and alkali soils that cannot be used to grow other traditional crops

Maximize gallons of ethanol per acre by staggering plantings of shorter season varieties to maximize use of harvesting and crushing equipment.

Basics of Sweet sorghum

As with most plants there are desirable characteristics that an ideal variety would have. There is never a plant that has all of these characteristics, so each farmer must decide what characteristics are important to them. According to the USDA [3] the ideal variety should:

- Produce a high yield of medium to large stocks
- Show strong, erect growth so it does not readily lodge during storms
- Contain a high percentage of extractable juice
- The juice should have a high percentage of sugars
- Resistant to diseases
- Tolerate drought
- Resist damage from insects.

So what is important to us here in Arizona? We experience monsoon storms that can lodge plants, so strong erect growth is important. It is difficult to harvest lodged plants and after they lodge the plants tiller, throwing up single or multiple new stalks. During the harvesting process tillered stalks are harvested. The tillered stalks are immature and contain 3 to 5 percent sugar, thereby decreasing the average sugar content of the extracted juice. For example, in 2011 we hand cut and tested stalks that had brix over 20%, but when the juice was collected after the harvest the brix was only 12. The explanation was that the harvesting equipment did not discern between erect stalks, lodged stalks, and immature stalks; it harvested all of them. The immature stalks contributed some juice, but very little sugar, which gave us our resultant brix of 12.

The most important characteristics in varieties are good sized plants with lots of sugary juice. The problem is a great crop of big sugary plants cannot be harvested during the same week because of limited capacity of harvesting and juice extraction equipment. For this reason the sequencing of plants will be discussed.

Single crop/Double crop/Multi-crop

Sweet Sorghum has traditionally been grown in the midwest, where it is planted in the spring, after the soil temperature reaches 65^oF. The crops have been photosensitive crops that put on seed heads and then mature when the length of the day reaches 12:30 hours of sunlight in the late summer. A common crop grown in this manner is M81E, a high producing variety developed at the Mississippi State University. This is a long season variety that typically grows 15-ft high and has stalks that are 1-inch in diameter. In Arizona this variety is planted in mid-May and harvested from mid-October through the first frost. It produces an average of 4,500 gallons of juice per acre at a brix of 12% to 16%.

The University of Arizona has been experimenting with a variety of short season varieties of Sweet Sorghum. Sugar T is one such variety. We choose this variety because its growth follows heat units, known as Growing Degree Days. Previous heat unit (HU) models were verified during the 2011 growing season by Martinez-Cruz, et al. [4]. The growth model estimates crop development based on cumulative growing degree days (GDD). A GDD is defined as the average daily temperature (^oC) minus 8^oC:

$$GDD = Ave Temp^{\circ}C - 8^{\circ}C$$

Average temperature data can be found in most agricultural growing areas from AZMET, and University of Arizona database of meteorological data. Please note that AZMET provides HU data, but it is crop specific for cotton, so you can not use this data. Sweet Sorghum crop growth has been found to stall when the mean temperature reaches 34^oC. This is due to heat stress. Therefore, if the mean temperature is greater than 34^oC, then the equation for calculating GDD's is:

$$GDD = 34 - 8 = 26^{\circ}C$$

The value of the HU analysis is to track maturity rates to predict when to harvest the crop. The goal is to have a continual harvest season. This is accomplished by working backwards. Continuous harvesting meets the goal to maximize the utilization of harvesting and crushing equipment. A sample farm was used to illustrate the use of staggered planting; the assumptions were as follows:

- 1,000 acre farm

- 15-day harvest window
- 2 days to take down, move, and set up crushing equipment near the next field.
- Continuous operation
- Plant when soil temperature (at a depth of 20-inches) reaches 12^oC (based on germination test done by Martinez-Cruz).
- Stop harvesting within 10-days of the first frost
- Grow a double crop of a hybrid, multiple crops of Sugar-T, and a field of M81E.
- Sugar T produces 35 tons per acre of biomass (no seed heads or leaves)

- M81E produces 40 tons per acre of biomass (no seed heads or leaves)

The 1000 acre farm was broken down into 6 planting dates, and associated fields, for Sugar T, one field for Hybrid, and one field for M81E (Figure 2). Because the primary goal was continuous harvesting and the time frames were equal (15 days) all of the fields were of equal size, 125 acres each. The resultant capacity of the harvesting and juice extracting equipment was 0.93 acres per hour in a 10-hour day; so the nominal capacity is 1-ac per hour. The average volume of biomass, without leaves and heads, is 35

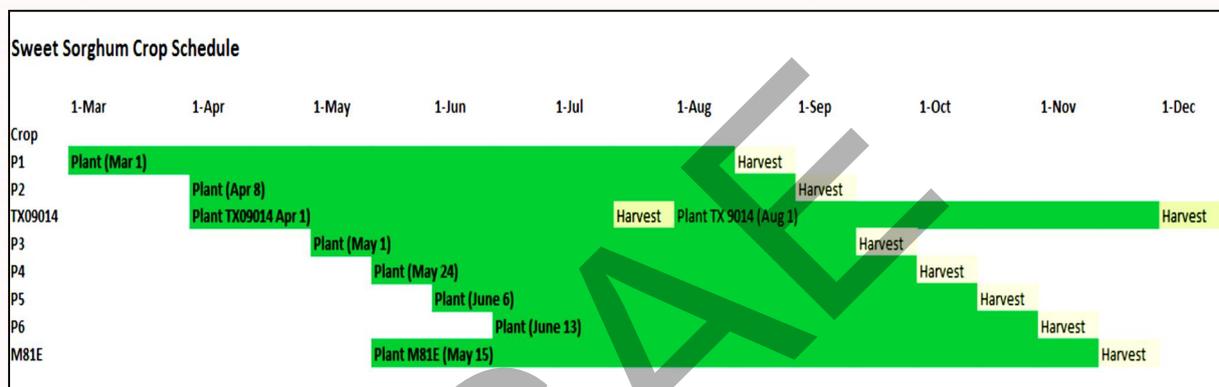


Fig.2. Staggered Planting

tons per acre through most of the growing season. The M81E crop is the last to be harvested, so its harvest period is a little longer to make up for the increase in biomass generated per acre. This volume of biomass, 35 tons/hour, justifies the use of a sugar cane harvester and the largest sized portable roller or diffusion system for juice extraction. The results of the HU analysis is illustrated in Figure 2.

Plant Physiology

At maturity the plants consists of roots, stalk-(s), leaves and seed heads. Each of these, and how they impact our ultimate goal of sugar juice production, will be discussed below.

Root System

The purpose of the root system is to stabilize and plant while transferring water and nutrients to the plant. The root system consists of primary, secondary, and supporting roots. The primary and secondary roots are the main roots to absorb nutrients and moisture. This differs from corn, where only the primary root is

bringing in nutrients and water. There are typically twice as many sorghum secondary roots as there are with corn, which makes it more tolerant during short periods of drought or for longer periods between irrigations. The University of Arizona has done several trials on water use by sorghum and has found that it can tolerate low levels of soil moisture, but if the plant is not adequately irrigated juice production will suffer.

The plant is supported by air roots that grow out of the first to forth nodes. The air roots are thicker, tougher, and have a higher tensile strength than the underground roots. Once they reach the soil they are able to support the plant and they absorb nutrients and water. Earthing-up the plants with soil can strengthen the plants resistance to lodging.

Lodging is a major problem because lodged plants are difficult to harvest and because of the natural tendency of the plants to tiller they cause the plants to shoot up new stalks. These stalks get harvested with the main stalks but do not contain very much sugar; brix is typically 3- to 5-percent. We believe this is the main reason that even though the field is harvested

with spot brix measurements above 16, the average brix of the product juice has a brix around 12.

Stalks

The stalk is the product we are harvesting. Ideal plants have single tall (3.5 to 4.5 m) stalks that are straight and have a large diameter (2.5 to 3 cm). Does this plant exist, sure, but after the stand is established and matures, can a field full of these stalks exist; only in our dreams. The University of Arizona has looked at the relationship between plant spacing and stalk diameter. Plant spacing's of 3, 6, 9, 12, and 18 inches were planted in multiple plots. At harvest there was a general relationship between spacing and stalk diameter, however there was an inverse relationship between seed spacing and juice yield, and the underlying goal is juice yield per acre, not pretty stalks. The agronomic section discusses seed and row spacing recommendations. Lodging was noted during the study, but it was difficult to relate lodging to plant spacing and stalk diameter. Lodging in Arizona is typically due damage that occurs during micro-bursts and dust devils. These types of storms can affect a 10-m wide swath of plants while leaving the rest of the field un-touched.

After harvesting, if there has not been a frost the stalks will ratoon. This can be taken as an advantage, allows for a second stalk to grow without re-planting. Some areas in Arizona, especially along the Colorado River have the potential to produce a second crop of sweet sorghum during the same growing season. A double crop study was done at the U of A Maricopa Agricultural Center. This study resulted in the conclusion that the minimal increase in juice extracted per acre did not justify double-cropping [5]. Additional research into planting dates, and the use of short season heat unit based plants instead of photo sensitive plants has opened the door to the economic feasibility of double cropping sweet sorghum in Arizona. This will be discussed in greater detail in the economics section of this report.

The bagasse, among other things, can be fed to animals, burned as a low density material, pelletized into high density energy pellets (9,000 to 11,000 btu/lb, depending on the process), or made into low density ceiling tiles.

Leaves are produced at each node of the stalk. They are obviously important during the growing season, but again, the goal of the plant is to produce a fermentable juice. If you are harvesting and crushing whole stalks the leaves contribute greatly (18%) to the volume of biomass that you are processing. This excess biomass slows down the crushing process. We have also noted that in some roller type presses the leaves get filled with juice, which is lost when the leaves are discharged from the rollers with the bagasse. The leaves do have a high protein content, so if they are harvested with the stalk the resultant biomass has a greater feed value for livestock.

Agronomy

Sweet sorghum is grown very similar to grain sorghum. The basic process is outlined below:

- Chisel, if necessary to break up any hardpans. Large farms are using rubber tracked tractors to reduce the buildup of hardpans.
- Disk to turn over the soil and reduce size of clods of soil
- Make furrows and buck the ends of the rows Plant
- Plant two to three seeds per foot using a vacuum planter
- Use a milo plate
- Depending on the type of planter/seed plate you have, you may need to fill some of the seed cups with wax or other materials to increase the spacing.
- Planting date
 - Tradition is when the soil temperature reaches 18^oC. A trial in a controlled environment found that over 80% of seeds germinated within 7 days when the soil temperature was just 12^oC. This is important because it allows us to plant earlier in the growing season, which extends the harvest season.

Irrigate

- Most sweet sorghum is grown using surface irrigation systems and standard furrows
- The total irrigation water requirement for sorghum is similar to cotton (36 to 42 inches per year). The plant is able to take

full advantage of monsoon rains, so they may result in a decrease in overall irrigation requirement.

- Irrigate when the available soil water capacity (AWC) is between 50% and 60% depleted. A study by Martinez-Cruz, et al. found that depleting the AWC to 80% resulted in water stressed plants and less juice, but did not result in a significant decrease in sugar content [4]. The volume of ethanol produced per acre is proportional to juice and sugar, so less juice is less ethanol.

Insecticides

- There are currently not any pests that will cause significant damage to the crop in Arizona at this time. There are several potential pests, including aphids and sorghum stem borer. :
- Aphids can suck the juice in the leaves, but the risk is low because of our high temperature (>24^oC)
- Sorghum stem borer's can cause stem damage.

Fertilizer

- Nitrogen: check field to see if it is limiting, if so, then add nitrogen as follows: top dress seedlings with Urea at 38 to 75 kg/ha; top dress spikes while you can still get in the field with urea at 150 to 375 kg/ha
- Iron: if the plant starts to yellow (chlorosis) the cause is probably an iron deficiency. This condition, iron chlorosis, can quickly limit plant growth, and it may not recover. Iron is readily absorbed through the leaves, so a spray solution should be prepared using 20 lb iron sulfate (copperas) in 100 gallons of water with a spreader sticker. Apply at a rate of 10 to 15 gallons per acre. Repeat every 7 to 10 days until green color returns.

Harvest Process

The harvesting method for small plots is tied to the juice extraction method, for example the smallest farms use full stock crushers. Today's commercial systems process 6- to 12-

inch long billets, so the harvesting equipment needs to be able to cut billets.

Small plots (<1 ha) are harvested as whole cane and crushed in a pre-1950 mill. The cane is either hand harvested or harvested using a cutter bar. The material is then loaded onto wagons for transport to a small mill. Most mills are mechanized mills that were originally designed to be horse or mule driven. Many users have since matched 1 to 5 HP electric motors to these mills.

Medium sized plots (1 to 20 ha) can be efficiently harvested using a forage chopper with the billets being blown into a forage wagon. If possible, remove all but one of the knives and add a counterweight to compensate for the removal of knives. This will result in 4-inch long billets, which is minimally acceptable. Any smaller and they begin to dry out before the juice is extracted. You should remove the heads with a high mounted cycle cutter bar before harvesting to minimize the need to hand remove the heads from the crusher.

Large plots (>20 ha) need to be harvested using a sugar cane harvester or heavy duty forage chopper, depending on final extraction process. They are a large hydraulically driven, self-propelled piece of machinery made to be out in the field harvesting cane. They are designed to cut an 8-inch billet and remove leaves. You may need to modify the bars on the final conveyor belt as we have experienced a loss of around 20% of the billets to getting caught in the standard sugar cane bars; they get carried around the end of the conveyor and drop off in the field. The sugar cane harvesters have a head cutting bar with an adjustable height so that you can adjust it to match cane height. It is important NOT to harvest the seed heads as they can negatively impact crushing equipment. Soil condition changes can result in changes in cane height.



Fig.3. Sweet Sorghum Harvested with Sugar Cane Harvester

The harvested cane is typically hauled to the processing plant in wagons that can side dump. There are specific cane wagons that can dump the required weight. Chili wagons have been used in Arizona. These wagons are used to dumping a material with high water content. When in use, the wheels are filled with water. The number of wagons depends on the distance to the plant and size of the plant. A complete discussion on harvesting is found in the Juice extraction section, as they are related.

Juice Extraction

A typical cane, with leaves removed, is approximately 76 percent juice. In the sugar cane industry their goal is to remove a minimum of 98% of the sugar, hence the large systems consist of 6 sets of three or four roller systems, each weighing 15 tons. The amount of energy used to drive these rollers is correspondingly very large. The sweet sorghum industry is not looking for 100 ton per hour production, and it is generally accepted that if you are removing 65% of the available juice you are doing a good job. Part of the reason is that the cane is smaller, so the pressure needed to extract the juice is higher, but because of the smaller stalk diameters the rollers are so close they get clogged if the feed rate is too high.

One must consider that the sugar harvesting season is around 270 days per year, so large permanent equipment can be economically justified. The sugar cane industry considers that one mill serves an area within a circle with a radius of 50-miles. Any further and the economics of hauling the cane to the mill do not equate. In order to be nimble, the sweet sorghum crushing equipment needs to be portable.

Consider a typical farm that is growing 1,000 acres of sorghum. The harvest season is 60 to 150 days, depending on the variety of sorghum grown. Assuming the worst case, M81, which has a harvest window of about 60 days, and an average yield of 45 tons per acre, then the crushing equipment, working 12 hours per day, would need to crush nearly 65 tons per hour. A single mill with this capacity would have to be fixed because equipment is large and power requirements are high 1,000 hp per 1,000 tons processed per day.

For large commercial operations there are three basic types of equipment for extracting the juice from the cane: roller, screw press and diffusion.

Roller Mills

A typical roller mill for sweet sorghum consists of two or three sets of rollers in series. These rollers may be preceded by a flailing system to break up the stalks ahead of the mill, but it is generally not necessary. The mills basically use pressure to extract the juice. Small to medium sized mills (<10 tons/hr) typically consist of two or three sets of three or four 3-ft long rollers that are 12- to 15-inches in diameter. The first impact on the cane is to break up the stalks, while the purpose of the remaining rollers is to extract or squeeze the juice from the pith, or bagasse. Typical rollers will have grooves cut in them to increase the pressure they are exerting on the cane and bagasse.

Larger mills can be built to match the size of the operation, but one must remember that depending on the location and crop being grown they are only in operation for 60 to 150 days per year. it is not practical to have a large outlay of capital for a piece of machinery that is only used 2 months per year. Also, because the larger mills have to be built on a specific site the cane has to be hauled to the mill, adding extra costs to the operation. Multiple small mills that are portable may be more efficient for projects with less than 1,000 acres of cane.

Screw Press

We have done field trials with screw presses. Their capacity to process cane is proportional to the diameter of the press. For example, the 16" press capacity is half that of the 24" press, which is half that of the 30" and so on. Screw presses up to 30" can be truck mounted and taken into the field. They would

need a power supply to run a 150 hp motor, but the press could process about 15 tons of cane per hour with a good (66%) juice yield. Vincent Press recommends using a twin screw because it will shred the cane and squeeze the juice more efficiently than a single screw press. If additional capacity is required they can be operated in series and parallel to increase capacity.

Diffusion

Think of diffusion as a large coffee percolator. Shredded pith or bagasse enters a rectangular box with a moving floor and hot water is sprayed from above. The water is

Figure 3. Sweet Sorghum Harvested with Sugar Cane Harvester

picking up the sugar and seeping through the floor into a tank. This percolating happens 6 to 8 times as the material moves from one end of the diffusion box (percolator basket) to the outlet. There is a roller press at the end to reclaim any water/juice still in the cane. Periodically the cane is fluffed to keep water moving through the cane evenly. By the time the bagasse leaves the plant over 90% of the sugar has been leached from the cane. The dried bagasse is burned to heat the water, so the process does not take much power. In fact it is rated at 100 hp per 1,000 tons of cane processed per hour. This is less than 1/10th the power requirement of a large roller press plant. The University of Mississippi is testing a scaled down version of a diffusion system in 2012. A review of the technology resulted in the conclusion that if basic scaling factors are followed there is no reason that a small, portable, diffusion plant could not be built to economically service the sweet sorghum industry.

KTC Tilby Separation System

The Tilby system is unique. The Tilby system understands that the economic value of an ethanol plant is the combined value of the fuel and byproducts. The Tilby system maximizes the value of the byproducts by breaking down the cane into parts that match a high secondary market demands for particle board, laminated strand lumber, cement board, fuel pellets, and natural waxes. The system splits the billets in half and then removes the pith, which contains the juice. The skin, or outer epidermal layer, demax, is then split off from the comrind. The juice is removed by a

combination of diffusion and rollers. The outer layers are made into OSB, OSL, particle Board, and even laminate flooring. The capacity of the system is determined by the width and number of parallel plants. The largest single plant is 50 tons/hr. Again, larger systems are achieved by having multiple parallel systems.

Byproduct Uses and Value

The economics section will show that the value of the byproducts, even at its lowest denominator is nearly equal to the profit potential from the ethanol. in fact, once reasonable business venture, Sweet Ethanol, has already been set up to process the cane, supply the juice to a ethanol plant, while retaining the bagasse. The raw bagasse has many uses. They are outlined below, starting with the easiest uses in its raw state to highly engineered renewable wood products.

- Animal feed
- Burn for energy
- Pelletize for energy
- Lumber products (OSB, OSL, MDF, LVL, and particle board)
- Laminate flooring
- Ceiling tiles

Animal feed

Sweet sorghum bagasse can be fed out as mash, pellets or ensilage. It has been shown to be a good filler feed. When fed to sheet, the mash and pellets were found to be 59- and 58-percent digestible. This product would be used to replace low quality feeds such as Sudan grass or bleached alfalfa. In Arizona, hay production has decreased by 11% since 2005, but there are still over 185,000 dairy cows and over a million cattle in Arizona. The range rating has dropped to 65% because of drought and fires, so the need for hay or hay substitutes like sorghum bagasse is high. The economics section assumed that the bagasse would be sold for \$40/ton, but recent prices for “cow hay”, which is a low quality hay have been over \$130/ton.

If the bagasse is going to be stored or shipped, then it needs to be pelletized. In 1975 the total cost to operate a 12,600 ton per year pelletizing plant was around \$850,000 [6]. This cost included paying just under \$40/ton for alfalfa. Therefore, the total cost minus purchasing the alfalfa was \$350,000. The cost

to build and operate the plant in today's dollars is approximately \$1,400,000, plus \$40/ton for the bagasse for a total operating cost of \$1,900,000. The cost per ton of pellets would be \$151.00, which is \$13.25 per 50 pound bag of feed.

The third type of feed is ensilage. This process is beneficial for long term storage of the bagasse without having to worry about the moisture content when storing the product. There is very little loss of protein and the fermentation in the bag increases the Total Digestible Nutrients (TDN), so the need to purchase supplemental protein is reduced. As the sorghum stalks are being squeezed the bagasse is being blown into "Ag-Bags". These are large plastic bags, typically 10-ft in diameter and 100-ft long. A specialized feeder system with a fan blows the still moist bagasse into the bag. Once filled, the bags are sealed and allowed to ferment. The resultant produce, ensilage, is then fed to cattle or sheep.



Fig.4. Ensilage "Ag-Bagger"

Burn for energy

The bagasse can be burned as a low density fuel, or made into pellets. Sugar cane plants derive their basic energy needs from burning the cane bagass directly. The sorghum can be made into pellets, see the feed section above for costs to make straight pellets. Zelen Environmental piloted the formulation of energy pellets made from sweet sorghum bagasse. They added recycled plastic and glycerin to the bagasse during the pelletizing process. The resultant pellets were very burnable and averaged over 10,500 btu/lb. Plain sorghum bagasse pellets have been found to average 8500 btu/lb. The ash content of the bagasse pellets is higher than coal, but both the pellets with glycerin and plastic and the plain pellets are competitive with coal. The price of coal is around \$30 per ton.



Fig.5. Energy Pellets from Baggase

Lumber Products

The outer layer of the sweet sorghum stalk, comrind, can be separated from the pith and outer skin and made into a variety of lumber products. KTC Tilby has a sorghum processing system that splits the billets in half, and then scrapes out the pith, leaving the comrind. The comrind can then be pressed into a variety of high and low density building products, including:

- OSB—Oriented strand board. OSB is manufactured in sheets made from cross-orientated strips of wood, or in this case sorghum comrind. They are typically used as sheathing in walls, floors, and roofs.
- OSL—Oriented strand lumber. The orientation of the strands results in structural lumber that is used as beams, headers, and studs.
- MDF—Medium Density fiberboard. This product is made into sheets and is denser than plywood and stronger than normal particle board
- Particle board. Lower density inexpensive material that is still widely used in the building industry.

SWEET SORGHUM TO ETHANOL BUDGET

The cost to grow sorghum and produce ethanol vary by distance from the ethanol plant. There are basic costs that are independent of location: cost to grow (excluding irrigation); the cost to harvest and extract juice (excluding

the cost to ship it to a plant to ferment the juice), and the cost to make ethanol (fermentation and distillation). The break-down the costs between growing, harvesting, and processing the juice are also financially independent.

Farming

The basic assumption is that the farmers will get paid to grow the sorghum plus a reasonable profit. The profit is tied to the opportunity to make a profit on a standard, substitute crop. For example, in Arizona the farmers would have been growing cotton, alfalfa, and small grains during the sorghum season. Over the past 5-years the cotton crop has resulted in an average per acre profit to the farmers of \$30/ac.

The difference is that the value of the juice is in the quantity of juice extracted AND the sugar content of the juice. Based on our experience growing the crop we have based the profit to the farmer on a crop producing 4,500 gallons of juice for the full season varieties and 3,500 gallons/ac of juice for the short season varieties. As demonstrated above, both of these varieties need to be grown to maximize juice production while spreading out the harvest season to maximize the use of the harvesting and juice extraction equipment. If the farmer chooses to put in extra effort, he can increase the volume of juice produced and possibly increase the brix. Keeping the crop well irrigated and fertilized can increase the juice yield. Seed selection could impact brix; so if they pay more for hybrid seed, they may end up with a higher sugar content.

As a recommendation, the base pay level for the material could be based on the following:

- Short Season—3,500 gal/ac
- Long season—4,500 gal/ac
- Short and long season—12% brix
- Maximum percentage of plants lodged—30%

If the average volume of juice extracted increases by 100 gallons at a brix of 12%, then that results in an additional 6 gallons of ethanol per acre. The raw value of the ethanol in 2013 was about \$2.20/gal. Therefore, the farmer could get an additional \$13.20/ac for every 100 gallons of juice produced, above and beyond the base amounts. A 2% increase in brix would result in an additional 35 gallons of ethanol. Under the same valuation, the farmer could be paid an additional \$38/ac for every percentage point increase in brix. New strains are claiming to produce juice with a brix as high as 20%, which would result in increased payments to the farmer over \$300.00/ac.

The cost to grow the crop is based on crop production budgets prepared by the University of Arizona for grain sorghum. These budgets were updated in 2013. The presented budgets are on a per acre basis and include labor, Figure 5. Energy Pellets from Bagasse materials, and equipment costs. The equipment necessary to work the fields, harvest, and extract the juice are based on the assumption that a viable growing size in the region is 1,000 acres. This does not have to be one grower as the harvesting and juice extraction equipment can be moved to different fields within the region. As previously described the assumption is that each field is growing a net of 120 acres.

The budget presents the costs to grow one crop of M81E, a double crop of a hybrid and series of short season varieties such as Sugar T. The profits are maximized when all three varieties are grown because it makes the most use of the harvesting and juice extraction equipment. Sugar T would be stagger planted through the growing season, and the hybrid and M81E would be planted in a single field, as illustrated.

The staggered planting allows for optimal use of the harvesting, juice extraction, and processing (fermentation and distillation) equipment as it extends this portion of the season to 135 days. The longer harvest/processing season results in smaller capacity equipment. For example, if only M81E is planted, then the harvest/processing season is only 30 days, so the equipment would need to be sized to have over five times the processing capacity.

The crop budgets were broken down in to the following categories:

- Returns :juice and bagasse
- Harvest costs: equipment, juice, haul juice
- Non-Harvest costs: tillage, irrigation, planting costs, and fertilizer
- Capital Investment: associated with equipment needed to grow and harvest sweet sorghum

Harvesting/Juice Extraction

The equipment necessary to harvest the cane and extract the juice is specialized equipment. The sweet sorghum industry is based on a single sugar cane harvester feeding a portable mill. The juice is then transported to

the central plant where it is mixed with the corn mash that has been through the scarification process.

This analysis assumes that a separate entity is custom harvesting and extracting the juice. A typical sugar cane harvester puts on about 5,400 hours per year. This results in major overhauls on a frequent basis. In Arizona a harvester taking care of 1,000 acres divided into 8 blocks would put on 820 hours per year. Therefore, used equipment can be used to service fields in Arizona. The University of Arizona used a sugar cane harvester with a track, standard equipment in Louisiana and most tropical areas growing sugar cane. The standard sugar cane harvester travels about 2.5 mph, and harvests a two rows of sorghum. This equates to two acres per hour, or a net delivery of 80 tons per hour to the juice extraction plant. The extraction plant would produce about 9,000 gallons of juice per hour, which would need to be hauled to the ethanol plant.

The byproduct of processing the cane, bagasse, is valuable. The question is who owns the bagasse. When looking at overall budgets, the income from the bagasse is almost equal to the income from the ethanol. In fact, if you did not have the income from the bagasse the ethanol does not pay the costs to grow the crop. Therefore, it is reasonable to think that either the ethanol plant would own and operate the harvesting and juice extraction equipment, or contract for this service. It was assumed that the ethanol plant contracts for this service. Therefore, the ethanol plant recovers the growing expense through selling the bagasse, or is able to use the bagasse pellets to power or provide heat to the plant 12 months of the year to reduce the cost to process corn into ethanol.

The enterprise budgets were divided into labor, operating, and machinery costs. The operating costs include inputs (chemicals, water, etc.) equipment maintenance and operating costs. The machinery costs include the capital investment costs for the equipment.

The cost to grow the crop is approximately \$618/ac.

The cost to harvest and transport the cane to the extraction plant; extract and haul the juice to the ethanol plant, and pelletize the bagasse is approximately \$280 per acre.

Once the juice is delivered to an ethanol plant, the cost to produce the ethanol is the same assuming the brix and gallons produced

per acre are the same. On a weighted average basis with 6 subfields of Sugar T and one subfield of M81E, he crops would produce a weighted average of 3,650 gallons of juice per acre. The value of the juice is directly related to the brix of the juice. The percentage of ethanol is approximately equal to half the brix. Therefore, a fair approximation for the relationship between gallons of raw juice and ethanol is:

$$\text{Quantity of Ethanol} = 3650 \text{ gal} * (12\% \text{ brix} * 0.5) = 219 \text{ gal / ac}$$

As described above, the process to make ethanol from the juice involves: fermentation, distillation, and dehydration. The cost for this process is \$0.8 per gallon, or \$175 per ac, based on the above assumptions of yield and brix.

The primary product is ethanol. The price of ethanol at the gas pump is typically 33-percent less than gasoline because the fuel value is 33% less. By fuel value, a gallon of E85 (85-percent ethanol, 15-percent gasoline) has 33% fewer BTUs than gasoline. Because of the need to inject more fuel to get the same power response, the use of E85 is also limited to "Flex" fuel vehicles. The Chicago Commodities Exchange tracks wholesale value of ethanol. On July 25, 2013 ethanol was selling on the exchange for about \$2.20 per gallon. The value of fuel from Sorghum is equivalent to \$482/ac. Working back, the juice value is \$0.13/gallon. Current fuel prices are about half those of 2013, so the value of juice is now about \$0.07/gallon.

Like the corn to ethanol process there are primary and secondary products that have value. For sweet sorghum the secondary product is bagasse. As described above, the value of the bagasse varies with the use. In Arizona, a standard and simple use is as cattle feed, either straight or pelleted. The market for cattle feed in La Paz County is nearby dairies, which operate 365 days per year. Although the bagasse could be fed directly to the cattle, because of handling and storage, we have assumed that the bagasse will be pelletized. The base value of the bagasse, as cattle feed is assumed to be \$40/ton. Assuming that the total stalk weighted average is 34 tons per acre and 45% of the juice is extracted, then the net weight of the bagasse is 18.6 tons per acre. The income from cattle feed would be \$744 per acre.

Income Analysis

The basic assumptions for this analysis are:

- Farmer paid all costs to grow Sweet Sorghum
- Farmer paid \$30/acre profit to grow crop
- Contract harvesting company paid costs plus \$10 per acre to harvest and process crop, and transport juice a maximum of 25 miles to ethanol plant
- Ethanol plant is an existing corn based plant that is equipped to add SS juice to process
- Average brix of juice is 12%
- Average volume of juice extracted is 3650 gal per acre
- Average mass of bagasse is 18.6 tons/ac

The net income from a sweet sorghum project, as presented, per acre of sweet sorghum in 2013 was \$137/acre. Today the value is negative \$100. The breakeven price of a fuel, excluding taxes, needs to be approximately \$154/gallon. The average fuel tax in the US is \$0.48/gallon.

Table 1 Income Analysis

Item	Cost/Income per ac
Grow Sweet Sorghum	(\$618)
Extract Juice and deliver to Plant	(\$289)
Make Ethanol out of juice	(\$175)
Wholesale Value of Ethanol	\$475
Wholesale Value of Bagasse	\$744
Net Income	\$137

As discussed above, if the farmer is able to produce a crop with a higher brix, then the value of that juice increases by \$38 per-centage point. Also, if the farmer is able to grow a crop that produces more juice than the averages stated (4,500 gal/ac for long season and 3,500 gal/ac for short season) then the value of the crop increases \$13.20 per 100 gallons per acre.

The net income from a sweet sorghum project, as presented, per acre of sweet sorghum in 2013 was \$137/acre. Today the value is negative \$100. The breakeven price of a fuel, excluding taxes, needs to be approximately \$154/gallon. The average fuel tax in the US is \$0.48/gallon.

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