Sweet Sorghum Production to Support Energy and Industrial Products

An overview of the cultivation, harvest, and marketing opportunities of sweet sorghum in North Carolina and the Southeast

Sweet sorghum is an attractive annual crop for southeastern farmers as it provides a high yielding source of fermentable sugars and vegetative biomass that can be used in a variety of industrial applications, including developing bioenergy markets. This crop is well-suited for the southeastern U.S. climate as it requires relatively low nutrient inputs, is drought-tolerant, and has an approximate 100-day production cycle that allows it to fit into many double-crop management rotations. Historically, sweet sorghum has been grown to support the production of molasses. There are, however, additional uses for this crop that could support new farming enterprises. In this extension factsheet, we will discuss the cultivation, harvest, and marketing opportunities of sweet sorghum grown in North Carolina and across the Southeast.

WHAT IS SWEET SORGHUM?

The term sorghum refers to multiple species of annual grasses that can be used to support the production of grain, forages for animals, or sugar. Sorghum bicolor is the species that is typically grown in commercial production and includes forage, grain, and sweet sorghums. The major difference among these sorghum varieties lies in how breeding has shaped where the plant expends its energy. For instance, sweet sorghum produces high quantities of soluble sugars contained in the stalk juices, forage sorghum produces high levels of cellulosic biomass with relatively low stalk sugars, and grain sorghum produces a large, starchy seedhead on a relatively short stalk. Figure 1 provides a visual comparison of grain and sweet sorghum. Each of these sorghum types serves a specific market. Our focus in this factsheet is on sweet sorghum and markets for the stalk’s soluble sugars.

SWEET SORGHUM CHARACTERISTICS

Sweet sorghum is a sugar crop, similar to sugar cane and sugar beets, that may show promise as a source of sugar for ethanol fermentation (Nathan, 1978). It is an annual crop in the grass family. It is noted for its high photosynthetic efficiency, adaptability to temperate regions, and drought resistance (Worley et al., 1992; Gnansounou et al., 2005; Martini et al., 2006). Individual stalks can be over 10 ft tall with dry ton yields surpassing 10 tons/acre annually. The pith or stalks can be mechanically pressed to release a sugar juice (12% – 22% sugar) that can be filtered and directly fermented by yeasts. The resulting ethanol can be separated through subsequent solids separation and distillation.
processes. The primary advantage of sweet sorghum over many bioenergy feedstocks is the reduced processing steps and inputs required for complete conversion, which may reveal improved economic benefits (Worley et al., 1992). Challenges in using sweet sorghum juice include a harvest time that is limited to three to four months per year and maintenance of juice stability. A number of reports suggest that juice extraction should occur soon after harvest and processing needs to take place immediately (Gnansounou et al., 2005; Kundiyana et al., 2006; Bridgers et al., 2011).

In addition to sugars, sorghum (*Sorghum bicolor* L.) can produce large quantities of cellulose, with relatively low levels of lignin, making it amenable to various energy processes. NC State University (NC State) field trials have shown upwards of 11 tons ac⁻¹ yr⁻¹ of bagasse (residual stalk material after pressing) is produced after juice extraction. Researchers have shown that both the total biomass and cellulose yields of sorghum are statistically greater than those of switchgrass (Paterson et al., 2009; Fike et al., 2006). Six-year average sorghum yields measured by our group have consistently surpassed 7.5 ton ac⁻¹ yr⁻¹ across North Carolina, even under drought conditions. Compositional analysis of sorghums indicate that 20% – 55% of their total dry weight consists of fermentable sugars (Tew et al., 2008; Billa, 1997) and cellulose accounts for 20% – 25% of their total dry weight (Worley, 1992). NC State data indicate a cellulose content of about 22.5% in the M-81E sorghum variety. Although switchgrass contains 30% – 35% cellulose (NREL, 2010), sorghum generally produces more cellulose per acre because of its higher overall yield. Accounting for cellulose-derived and native sugars, as much as 70% of sorghum dry weight can be fermented into fuels.

**CULTIVATION**

The cultivation of sweet sorghum is similar to that of traditional row crops grown in the Southeast. Most of the equipment required for planting and cultivation is available in the region and familiar to most growers. The following section provides information on the growth of sweet sorghum for southeastern growers.

**Preplanting Operations**

Sweet sorghum has shown an ability to perform well on marginal to poor soils and can be planted using clean tillage or no-till operations. If heavy residues are present in the field, some tillage—such as strip tillage—would allow the soil in the planting furrow to warm faster. Experience at NC State has shown sweet sorghum had marginal germination in poorly drained soils and including soils in the NC coastal plain and piedmont. Preplant herbicide application is advised to neutralize existing vegetation as well as control potential weedy grass outbreaks early in the production cycle. Herbicide application is discussed in greater detail below.

**Seeding Rates and Planting Dates**

Typically, sweet sorghum prefers a fairly warm soil, approximately 65°F, and is generally easy to establish in most conditions. This will generally push planting dates to the late April through early May time frame. To maximize yield, it is important to plant sorghums as early as possible to take advantage of the early summer days providing maximum sunlight. Planting as late as mid June is possible, and yields in excess of 8 dry tons/acre have been achieved in the NC coastal plain. With such a late planting date, however, plants could be affected by an early frost, especially in mountainous regions.

Either grain drills or row crop planters can be used to plant sweet sorghum seed. Row spacing between 20 and 38 inches can be used. Typically, narrower rows are best. If weedy grass pressure is a concern, vegetative shading can be used to help control weed pressure. A final stand population of between 40,000 – 50,000 plants/ac is a good target for sweet sorghum. Depending on the variety, this population will equate to 2.5 – 4.0 lb/ac when germination and survivability of the seed are considered while determining the target planting population. A planting depth of 0.75 to 1.25 inches should be targeted.

**Fertilizer Requirements**

One of the greatest benefits of sweet sorghum is its efficient use of soil nutrients, particularly nitrogen. Many researchers have attempted to study the nitrogen response of sweet sorghum. Most researchers have concluded that nitrogen application has little impact on sugar production. Additionally, while there is a biomass response associated with additional nitrogen application, the response does not appear to improve above an N application rate of 60 – 90 lb/ac, depending on the soil type.
All sorghums are susceptible to nitrogen burn, and side-dressing is the preferred method of application. Broadcast application of granular nitrogen is effective only when it occurs prior to planting to prevent leaf burn and maintain a uniform fertilizer distribution pattern. Top-dress application of liquid nitrogen should not be considered because of the potential for serious leaf burn. Using drop nozzles to apply liquid nitrogen below the leaf canopy would be acceptable.

Lime application is recommended in acidic soils (pH below 5.8). Sweet sorghum performs very poorly in acidic soils, and tremendous yield increases have been observed by applying lime to increase the soil pH if acidity is a problem. Phosphorus and potassium application should be considered based on the results of soil tests and agronomic recommendations provided by state departments of agriculture.

**Water Requirements**

Sweet sorghum is considered a drought-tolerant crop, but it does need water. Although sweet sorghum can survive long periods of dry weather, eventually it will require water to recover and survive. Sweet sorghum has the unique characteristic of being able to essentially “idle” its growth and metabolic processes when it feels water stress. When soil moisture is abundant again, the crop will resume its growth. Biomass will increase to a point as the amount of available soil moisture increases. The interaction between water availability and sugar production, however, is less clear (i.e., more water does not equal greater sugar production). Approximately 20 – 25 inches of rainfall over the nominal 100-day growing cycle will produce a promising biomass yield.

**Weed Control**

Effectively controlling weed competition is one of the most challenging aspects of sorghum production. Competition from weedy grasses, such as Johnsongrass (*Sorghum halepense*) or Texas panicum (*Panicum texanum*), is especially difficult because herbicides that are effective against these weed species will either kill or severely harm sweet sorghum as well. Broadleaf weed control can be accomplished using herbicides specifically targeted for nongrass weed species.

One of the most effective means of controlling weeds in sweet sorghum is preventing the weed populations from occurring. A successful system would involve using a seed that has been treated with a safener. A safener is a coating added to a seed that prevents a specific herbicide from targeting that particular plant. One of the most common safeners used on sorghums is Concep® (Syngenta AG). Concep® treated seed can be exposed to Dual or Bicep II (both metolachlor herbicides) without injury (Figure 2). A metolachlor herbicide would then be applied at the same time as planting operations to prevent new weeds from germinating for a brief period. The goal of this herbicide application is to hold back the weed pressure so the sweet sorghum can become established and out-compete future weeds. A broad spectrum herbicide, such as glyphosate, can be mixed with the metolachlor to kill existing vegetation in the field—a preplant burn down.

From a post-emergence perspective, grass weed control is limited to two options. Hooded sprayers can be used to neutralize weed pressure between the rows. The other option is the use of mechanical cultivation (i.e., a row cultivator) to physically uproot the grasses. Both of these options, however, have a narrow window when they can be used as sweet sorghum’s height will limit the opportunity for weed control. Eventually, sweet sorghum becomes tall enough to shade out competing grasses. Additionally, evidence suggests that sweet sorghum is effective in shading out weeds and weed pressure in the field will be reduced in the year following sorghum production. This could be an important benefit in the rotational management of crops with high populations of herbicide resistant weeds.
Other Considerations

Sweet sorghum grown in North Carolina has shown susceptibility to chinch bugs and worms (particularly army worms). Both of these insects can be controlled with pesticide application, and appropriate application rates can be found in your state’s pesticide handbook (for North Carolina, that’s the agricultural chemicals manual: http://ipm.ncsu.edu/agchem/agchem.html). Sweet sorghum is susceptible to any pest or disease that can attack grain sorghum. Because grain sorghum is a more widely-grown commercial crop in the United States, a more extensive body of literature discussing production concerns is available. Solutions to some sweet sorghum field issues may be found by reading extension publications developed for grain sorghum from across the United States (Buntin, 2012; Cronholm et al., 2007).

Sweet sorghum is a fairly tall, thin-stalked crop. Like corn, it is highly susceptible to lodging when exposed to high winds. Unfortunately, North Carolina and much of the Southeast is prone to experiencing tropical weather systems when sweet sorghum is at its peak maturity. Although little can be done to prevent lodging under these conditions, the best strategy may be to harvest early if the crop is threatened and time allows.

Deheading is the practice of removing the grain head from the sorghum plant before seed develops. The theory is the sweet sorghum plant will consume stalk sugars to produce the starchy seed head, so preventing the seed head from developing will promote higher stalk sugar concentrations. This topic has been researched and the results have been very mixed, partly because variety plays a large role in the outcome of the deheading operation. Also, some research suggests that while the stalk sugar increases, the ability to extract the sugar decreases after deheading. Because the research has mixed results and considering the difficulty of deheading a plant over 12 ft tall, it does not seem beneficial to engage in deheading operations until further research shows otherwise. Sterile sweet sorghum varieties that do not produce a seed head could be cultivated to avoid a deheading decision.

HARVEST

Harvesting sweet sorghum can be a difficult process as there are limited mechanized systems to support this aspect of the production cycle. Sweet sorghum has traditionally been manually harvested using machetes or axes to cut individual stalks. The stalks are then collected and moved to a central location for further processing. The University of Georgia has estimated that over $540/acre is required to cover such manual labor costs.

Mechanized harvesting of whole-stalk sweet sorghum for the most part relies on expensive or antiquated equipment. Corn binders, which cut whole stalks and put them in bundles across the field, are a potential mechanized solution for whole-stalk sweet sorghum harvest. These machines, however, have not been widely used in the United States in many decades. Additionally, sugarcane harvesters could be used as well, but these are among the most expensive agricultural machines in the world. New specialty machines have been designed for sweet sorghum whole-stalk harvest, but they remain under development and have not reached commercial status.

If whole-stalk harvest is not an objective, there are two methods of mechanized harvest available. These methods use readily available, traditional agricultural equipment and have been demonstrated by the authors. The first is the use of a mower conditioner and round baler to collect stalks in bale form from the field. A major concern with this method is developing an efficient means to extract juice from the baled material if juice separation is desired. Most likely baling is an option only if animal feed or cellulosic fuels are products of interest. The other mechanized system is the use of a forage chopper to cut standing sorghum into small pieces for collection into a wagon (Figure 3). One of the limitations of this approach is the inability to easily
fractionate the different components (e.g., seedheads, leaves, pith, and rind) of the crop.

**JUICE EXTRACTION**

One of the primary benefits of sweet sorghum production is that it provides a direct source of aqueous fermentable sugar. These sugars are contained in the stalk juice and must be extracted through some form of crushing or squeezing operation. Perhaps the oldest and most common means of juice extraction is passing whole stalk pieces through a set of rollers. Studies using this type of press have shown that typically less than 50% of the juice is collected and the press relies heavily on manual labor. Additionally, the leaves should be removed from the stalks prior to crushing. The leaves contain few soluble sugars. If the leaves are very wet and green, they introduce more water during juice extraction and dilute the sugar solution. If leaves are very dry and brown, they seem to act like a sponge, soaking up juice. Removal of the leaves will improve extraction efficiency. Although this system is labor intensive and lacks efficiency, it is simple to implement and requires a low capital investment.

Another method for juice extraction that we have demonstrated is passing material harvested with a forage chopper through a screw press. Although a screw press is an expensive investment, using this method significantly improves throughput and reduces labor cost. Also, forage chopped material provides an improved way to separate nonjuice-containing plant fractions prior to squeezing. Because the pith and rind sections of the plant have different densities, it may be possible to separate the lighter, sugar-laden pith from the rind with sieves, screens, or airflow.

A very important factor to remember when handling whole stalks, chopped material, and raw sorghum juice is that all three contain a highly concentrated sugar solution that is a preferred growing media for several microorganisms. It is important to use freshly squeezed juice as soon as possible to prevent other microorganisms from either consuming the sugars or creating an environment that will inhibit desired juice fermentation organisms from flourishing. While stalk material is difficult to handle and preserve, once the juice is extracted, preservation methods such as refrigeration can be used to store the juice for short periods of time (up to several weeks).

**PRODUCTS**

**Molasses**

Molasses is the traditional agricultural product derived from sweet sorghum. Molasses is made by squeezing the sugary juice out of the sweet sorghum stalk then dehydrating the juice to make a thick, viscous sweetener. When traditional cane press technology is used, it is advisable to strip the leaves off the sweet sorghum prior to crushing as sugar recovery will increase by as much as 30%. As the juice is boiled, constant stirring is required to prevent the molasses product from burning. The juice slowly changes colors from a greenish color to a deep brown as the sugars concentrate and crystallize.

**Fermentation Platform/Ethanol Feedstock**

The value of sweet sorghum lies in the relatively high concentration of sugars contained in the watery stalk juice. Typically, sugar concentrations within expressed juice will range between 12% – 20% for most sweet sorghum varieties. These sugars are a mixture of sucrose, glucose, and fructose with the exact ratio varying between different sorghum varieties. Similar to the molasses process, the juice must be expressed from the stalk. With the sugars already contained in the juice, it is possible to begin fermentation of the solution for ethanol simply by adding yeast. For the fermentation to be successful, several factors must be considered, such as sterilization, yeast strain selection, reaction temperature, and pH. Results of our research have shown fermentation can be completed within 24 hours with 90% of sugars converted to ethanol simply by adding yeast to freshly pressed juice (Bridgers et al., 2011).
In addition to ethanol production, the sugars from sweet sorghum can be used to support a wide array of fermentation products. Hydrogen and butanol are two such energy products that have been produced from sweet sorghum sugars. Additionally, lactic acid, lipids intended for biodiesel production, and acetone are other industrial compounds that have been generated by fermentation processes using sweet sorghum sugars as a feedstock.

Animal Feed

Sweet sorghum can be used as an animal feed if proper storage considerations are followed. The whole stalk in the field or the bagasse (the solid material left after juice extraction) are candidates for animal feed. Both of these sweet sorghum materials contain high levels of residual sugars that will lead to rapid spoilage from microbial activity. Therefore, the material must be ensiled if not immediately used. Ensiling involves either tightly compacting chopped material or wrapping baled material in plastic to limit exposure to oxygen. This creates an anaerobic storage condition that allows specific bacteria to grow and make lactic acid. Eventually, the acid concentration is high enough to kill off all microorganisms, including the bacteria producing the acid. The material would then be in a state of preservation.

Sweet sorghum is generally considered a low-value feed ingredient as both the starch and protein content values are relatively low. However, the high tonnage and ability to produce significant tonnage under adverse weather conditions are highly favorable characteristics. If sweet sorghum is mixed with an additional starch source, it can provide similar performance as corn silage when fed to dairy cattle. Efforts to quantify its value to the swine industry are underway.

Higher Value Products

Many of the products that follow are under development and currently being researched to provide future markets for sweet sorghum (Whitfield et al., 2012). Perhaps one of the most interesting is the use of sorghum’s allelopathic properties to develop new, natural herbicides. Alleopathy refers to the ability of a plant to produce compounds that affect the growth of other plants in either a positive or negative way. There are compounds in sorghum that have medicinal uses, such as potential diabetes treatments. Additionally, waxes produced in sorghum can be used to make edible films and coatings for use in the food manufacturing industry. Finally, the bagasse from sorghum juice processing has been successfully demonstrated as a medium for mushroom production.

Although the primary product development theme attached to sweet sorghum is access to a source of directly fermentable aqueous sugar, it is important to value the high tonnage of cellulose produced by this crop. The cellulosic fraction has the potential to play a critical role in the development of advanced second generation biofuels. From a cellulosic ethanol perspective, sweet sorghum has a tremendous feedstock advantage because it has relatively low lignin and hemicellulose contents and the structure of the cellulose is such that fuel conversion could be fairly straightforward when compared to other grass feedstocks.

PRODUCTION BUDGET

The cost to produce sweet sorghum has similarities to corn silage budgets with the exception that, in general, the inputs will be lower. Soil samples for potential fields will influence the application of nutrients, and insecticide values may vary as well, based on infestations that will vary by year. The budget prepared in Table 1 is based on no-till production of sweet sorghum in the NC coastal plain. The presented budget is not a true enterprise budget because markets and product valuation for sweet sorghum are highly variable and not fully known at this time. This budget, however, does provide a general means to determine the potential costs incurred for producing sweet sorghum.

Figure 5. Baling sweet sorghum for animal feed.
REFERENCES AND RESOURCES

The following materials either were used in the development of this factsheet or can be referenced to acquire additional knowledge about sweet sorghum production.


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Table 1. No-Till Production Cost for Sweet Sorghum in North Carolina—2013

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