

## Biomass production and ethanol potential from sweet sorghum

### Background

Potential feedstocks from crop-based energy production systems range from starchy and sugary tuberous crops to woody, oilseed, or herbaceous crops (including corn, sweet and grain sorghums, and several grasses). An important characteristic of biomass crops is that the ratio of energy of the biomass product be large compared to the energy used to produce the crop. Because one of the most costly inputs in the latter component is nitrogen (N) fertilizer, any evaluation of potential energy crops must emphasize N inputs. Given its high N requirement, corn is not likely to meet all future ethanol demands. Corn also is limited by the inefficient conversion of starch to ethanol and by environmental and conservation considerations such as suitable land use.

Ethanol derived from crops other than corn would increase farm diversity and sustainability. Sweet sorghum, which is biologically competitive with corn, has been shown to have a more beneficial energy balance than corn. To produce comparable ethanol yields, 190, 140, and 90 kilograms N per hectare, respectively, are required for corn, grain sorghum, and sweet sorghum production. (In Minnesota studies, N rates greater than 56 kilograms per hectare [50 pounds per acre] showed no effect on yield.)

Such considerations regarding efficient use of resources increase the economic potential of sweet sorghum, which has enormous growth rates and can reach heights of eight to 12 feet (see photo). Sweet sorghum cultivars have proven exceptionally adaptive to a wide range of environments for a grass of tropical origin, making it a strong candidate in the search for energy crops. Depending on the number of frost-free days, the location grown, and the

type of cultivar, sorghum may be superior to corn in production of fermentables. So far in the United States, research has emphasized sugar production, syrup production, and forage use, and efforts to preserve sweet sorghum's genetic base have emphasized disease resistance and adaptability. But a wealth of variation exists in the *Sorghum bicolor* races, and these variations need further study.

The objectives of this study were to evaluate the productivity of a group of sweet sorghum cultivars of varying maturity and morphology, to determine sugar accumulation patterns in the cultivars, to examine cultivar growth patterns, and to evaluate sweet sorghum as an energy crop by producing ethanol from the cultivars processed as silage. Ethephon and glyphosine were evaluated for reducing lodging and increasing sugar concentration in the stalk.



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**Budget**  
\$29,932 for year one  
\$31,500 for year two  
\$33,075 for year three

**Sweet sorghum cultivars Grass! (left) and Theis (right) reached heights of 11 feet at the Chariton location in 1991.**

## Approach and methods

Cultivar experiments were conducted from 1991 to 1993 with 11 cultivars grown at two locations: the ISU Agronomy and Agricultural Engineering Research Center near Ames and the McNay Research Center near Chariton. These sites offer different land types and fertility factors, which constitute different production scenarios. Prior to establishment of the sweet sorghum plots, Ames fields were in the soybean year of an oat-corn-soybean rotation. The average number of frost-free days annually was 160. Chariton plots had been in conventionally managed red clover with one year of oat production prior to sorghum planting; production in this area is primarily devoted to livestock. The average frost-free season at this location was 165 days. Rainfall at Chariton is about 15 percent higher annually than at Ames.

**Experimental design:** Eleven cultivars of *S. bicolor* were selected to include a wide range of maturities, morphologies, and breeding histories. The cultivars, from earliest to latest, were Waconia, Kansas Orange, Smith, Sugar Drip, Cowley, Theis, M81E, Dale, Keller, Wray, and Grassl. Developed at various locations, several of these are dual-purpose forage and syrup cultivars.

Fields at the Ames location were chisel-plowed in the fall. The seedbed was prepared in the spring with a field cultivator and a harrow in one pass. Fertilizers and herbicides were applied each year; the target seeding rate was 16 plants per linear meter of row (about 2.5 inches between plants). Rows were spaced 75 centimeters (about 30 inches) apart. At Chariton, the same cultivars were used, but the field was disked and harrowed in the spring. All fields were cultivated once per season for weed control. The experimental design at both locations was a randomized complete block design. There were four replications at both locations in all years except 1991 at Ames, when five replications were planted and two harvested.

Cultivars Theis, Kansas Orange, Dale, and M81E were grown at the Ames site in 1991-

1993 with rates of ethephon of 0, 1, 2, and 4 ounces per acre applied to shorten lower internodes and reduce lodging. Dry matter yield, total sugar, and plant height were measured.

**Field data collection:** Each season, investigators took (1) stand counts (at the season's beginning and end), (2) leaf and stalk development (every ten days), (3) Brix, or percent soluble sugars readings, (4) maturation patterns (throughout the season), (5) percentages of plants lodged greater than a 45° angle (at harvest), and (6) weights of whole-plot harvests.

Brix readings were taken every 7 to 10 days. Plots were harvested with a forage chopper into a weigh wagon. A forage sample was weighed, microwaved to suppress respiration, dried, and re-weighed to determine moisture percentage. Dry material was ground and stored for later compositional analysis. When glucose to sucrose ratios for 1991 and 1992 samples were not as expected, a portion of the subsample was frozen for later analysis; the remainder was treated as described above to determine moisture percentage.

Chopped forage of two replications of the cultivars harvested at Ames were ensiled for alcoholic fermentation in all three years of the experiment. In the first two years, 35 pounds of material per cultivar was inoculated with a yeast strain, acidified to a pH of about 4.0, and packed in containers. In the third year, 1.33 pounds of material was prepared via this process. Anaerobic conditions were created for these "mini-silos," which were sampled at approximately two and four months of age.

**Laboratory methods and statistical analysis:** Dried or frozen plant samples were analyzed for sugars. Reducing sugars consisting of glucose and fructose along with a nonreducing sugar, sucrose, were determined calorimetrically. Sugar concentrations of samples were then calculated, along with percentages and determination of sugar yields on the basis of land area. Sugar analysis was performed on all plots of all replications at each location.

Fermented silage samples were analyzed for residual sugar, and high pressure liquid chromatography was used to analyze ethanol and volatile fatty acid concentrations. Potential ethanol production was calculated using the total sugar yields for the two cultivar replications that were fermented. The General Linear Model procedure and Analysis of Variance procedure (SAS) were used to determine the statistical significance of cultivar, location, and year effects on the attributes measured. Seasonal changes of Brix values and plant morphological measurements were considered as repeated measures within a plot (i.e., one plot was measured six times during the season).

### Findings

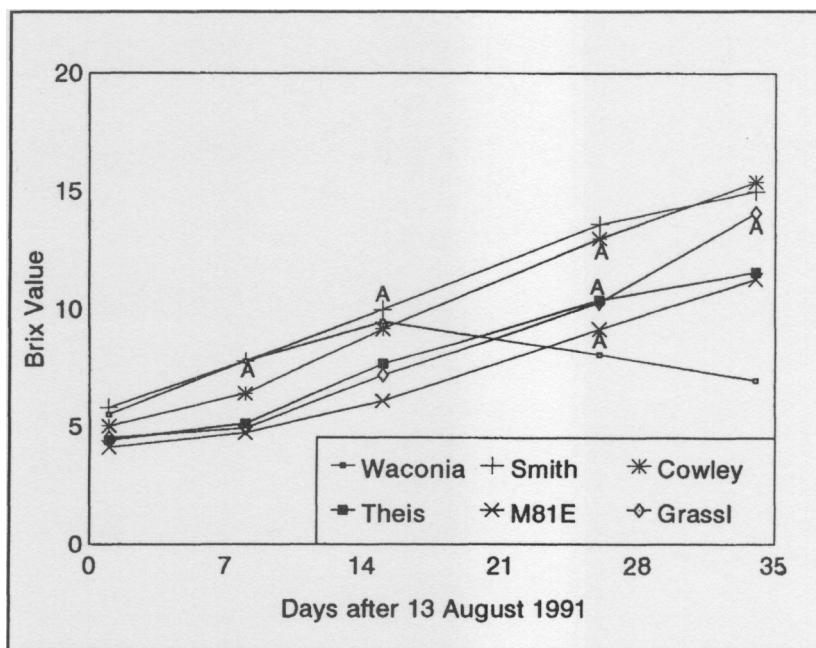
The number of days to anthesis (full blossom) for the 11 cultivars grown in Ames provides an indication of relative maturity (see Table 1), although cultivars differed in rates of seed head development during the post-anthesis development period. Maturation was linked to other yield characteristics. The cultivar Smith had the highest percentage of dry matter at harvest, whereas Grassl yielded the most dry matter over all years and locations. Yield characteristics differed among locations, years, and cultivars due to differences in site fertility, latitude, and climatic differences in years, but the relative rank order of the cultivars remained rather consistent.

**Table 1. Average of yield trials for eleven sweet sorghum cultivars grown at two Iowa sites for three years. Cultivars are presented in order of maturity.**

Cultivar	Days to anthesis	Percent moisture	Dry matter	Total sugar	Potential ethanol
			—pounds/acre—	—gal/acre—	
Waconia	83	77	11,071	3,929	267
Kansas Orange	83	73	14,286	5,446	371
Smith	88	73	13,661	5,982	407
Sugar Drip	93	76	14,107	6,607	449
Cowley	100	75	14,554	6,875	468
Theis	101	74	14,911	6,607	449
M81E	104	76	16,161	6,429	437
Dale	107	77	14,107	6,964	474
Keller	107	75	15,982	7,411	504
Wray	107	75	15,625	7,143	486
Grassl	108	75	16,250	6,786	462

**Dry matter production:** Two early-maturing cultivars, Waconia and Kansas Orange, had the least dry matter yield of the cultivars, and Waconia was less than Kansas Orange. Three late-maturing cultivars, M81E, Grassl, and Wray, stand out from all others as high yielding (Table 1). Mean dry matter yields in 1991, 1992, and 1993 were 13.3, 20.0, and 10.3 thousands of pounds per acre, respectively. The greatest dry matter yields were about 21,000 pounds by the three latest cultivars, Keller, Wray, and Grassl, in 1992; the least dry matter yield was 6,000 pounds from Waconia in 1991. Results of this and other studies suggest that study site can affect maturities of cultivars, producing discrepancies due to cultivars' differences in temperature sensitivity and photoperiod, and the fact that temperature initiates a photoperiod response of reproductive growth.

**Sugars production:** As a mean of three years at two locations, Keller produced 741 pounds of sugar per acre, which is equivalent to 500 gallons of ethanol, assuming 14.7 pounds of sugar equals one gallon of ethanol. In 1992, Keller produced the equivalent of 790 gallons of ethanol per acre. Most of the seven Gulf



**Fig. 1. Brix (percent soluble sugars readings) values for six cultivars over five dates in 1991 at Ames. The symbol A on the figure represents the date of anthesis.**

Coast cultivars approached the yield of Keller. Of the four early cultivars, Sugar Drip approached sugar yields of the Gulf Coast cultivars and was about two times greater than Waconia.

Figure 1 shows how the cultivar varied in sugar accumulation during the season. Total sugar concentration of stalk internodes was measured during the season in order to better understand how sugar accumulated. During the early part of the season, the lower nodes had greater sugar concentration than higher internodes. As the plant aged, sugar concentration in the lower nodes progressively increased from about 5 to 11 percent sugar, but sugar of the upper internodes increased more rapidly, reaching values of about 14 percent. Sugar concentrations of internodes of early cultivars such as Waconia and Kansas Orange began to decline as the head reached the milk stage, probably because of the large need of sugars to make starch in the seeds. In contrast, the later southern cultivars reach the milk stage and maximum sugar concentration near the time for harvest. These variations in sugar accumulation patterns along with much greater size explain the greater sugar yield of southern cultivars when grown in the Midwest.

The proportion of reducing sugar to sucrose varied during the season. The more metabolically active reducing sugars were relatively more abundant than the storage sugar sucrose in young, expanding internodes. After internodes had elongated and the season progressed, the relative concentrations of sucrose increased. There were differences between cultivars in the relative amounts of the two types of sugar. For example, Keller and Wray had about twice as much sucrose as reducing sugar near harvest. On a weight basis, sucrose produces about five percent more ethanol than do reducing sugars. At Chariton, mean percentage of total sugar in the dry matter was 45 percent and at Ames the value was 43 percent, even though dry matter yields were slightly greater at Ames. This indicates the need for relatively high temperatures for maximum sweet sorghum development, as does the greatly reduced yields of dry matter and sugar during the wet and cool season of 1993.

During the season, the progressions of leaf, node, and plant height were measured. These data helped describe how sweet sorghum develops during the season and how cultivars vary. Southern cultivars reached heights of 12.8 feet with 14 nodes in 1992, whereas in 1993, their height was 9.2 feet with 11 nodes.

#### **Height reduction and sugar ripener treatments:**

Ethephon, a plant growth regulator, when applied at a rate of two ounces per acre as an over-the-top broadcast spray when sweet sorghum was about four feet high, reduced length of lower internodes and reduced plant height about 1.5 feet. The treatment did not reduce dry matter or sugar production. There was a reduction in amount of plant lodging.

A sugar ripener chemical, similar to that used in Hawaii, when applied to the whorl of sweet sorghum when the head was one inch long, increased concentration of sugar in the stalk by 25 percent. When sprayed as a broadcast application, considerable leaf damage resulted. Methods were devised to limit application to the whorl, although tests were not run.

#### **Implications**

Energy crises in recent decades have prompted sporadic interest in energy production from crops in the United States. The Clear Air Act has rekindled this interest from an environmental standpoint. Research programs on biofuels are intended to reduce dependency on imported oil and increase renewable fuel production and consumption. These technologies have more than doubled their contribution to the nation's energy production in the past 20 years.

The economic viability of biofuels, utilization of its co-products, and cellulosic feedstock conversion all require additional research. Advances in this technology—more specifically, use of sweet sorghum as a biomass crop for fuel ethanol—could significantly affect rural economies and add value by incorporation of energy crops into farm plans, increased employment opportunities resulting from local feedstock production and processing, and decreased government subsidies.

More than 95 percent of the fuel ethanol produced in the United States is made from corn; 7 percent of gasoline consumed is an ethanol blend. More than 9.1 billion liters are projected to be consumed by the year 2100, and the cost is projected to decrease, to approximately \$0.18 per liter by then. Currently, the strongest market for ethanol is in the Midwest. Sweet sorghum culture, while similar to that of corn or soybeans, fits temporally between the end of soybean planting and the beginning of soybean harvest, yet sweet sorghum uses relatively low levels of N fertilizer. Moreover, growing sweet sorghum for a liquid fuel provides the Midwest with a third, non-grain crop for corn-soybean areas.

In the future, ethanol's value as an alternative fuel is expected to increase. Ethanol from sweet sorghum would reduce the need for government support of grain prices, stabilize oil prices, and partially replace oil with a renewable source of energy. This study has helped to define the type of sweet sorghum that would produce maximum sugar yield in the Midwest. Corollary studies on methods of fermentation and distillation indicate the technical and economic feasibility for on-farm fermentation of the sugar of sweet sorghum forage to ethanol and for the distillation of the ethanol to an ethanol-water solution that could be transported to a central facility for making fuel-grade ethanol.

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