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Sweet Sorghum as Feedstock in Great Plains Corn Ethanol Plants: The Role of Biofuel Policy

Richard Perrin, Lilyan Fulginiti, Subir Bairagi, and Ismail Dweikat

This research examines whether sweet sorghum, a crop considered more drought-tolerant and suitable for semi-arid areas than corn, could result in an economically viable sweet sorghum ethanol pathway in the Great Plains. We find that that if the D5–D6 RIN price spread exceeds the $0.35/gal recently experienced, the benefits of the pathway would be equivalent to about $90/acre of sweet sorghum, or $0.38/gal of ethanol. Because of sparse cultivation potential, only four the six existing plants in the Nebraska–Colorado High Plains area might expect transportation costs to be low enough for economic feasibility.

Key words: RFS2, RIN prices, sweet sorghum syrup

Introduction

Sweet sorghum is a subspecies of sorghum (*Sorghum bicolor (L.)* Moench) developed for its high stalk sugar content rather than for grain production. While some ethanol plants in the United States use grain from grain sorghum cultivars as a feedstock, to our knowledge none currently use juice from any sorghum cultivars as a feedstock. Wortmann and Regassa (2011) proposed sweet sorghum as a biofuel feedstock crop for the Great Plains, where the drought-tolerant crop could thrive without irrigation and little—if any—fertilizer. Here we examine the economic feasibility of using fresh sweet sorghum stalks in the Great Plains as a seasonal feedstock substitute for corn grain in corn ethanol plants during a two-month harvest period. The economic feasibility of this pathway may be enhanced by the structure of prices for Renewable Identification Numbers (RINs) that are used by obligated parties to demonstrate compliance with the 2008 Renewable Fuel Standard (RFS2). Ethanol from sweet sorghum pathways will presumably qualify as an advanced biofuel under the U.S. Renewable Fuels Standard (RFS2), thus generating more valuable D5 RINs than the D6 RINs generated by corn ethanol.

Dedicated sweet sorghum ethanol production plants in the Great Plains are unlikely to be competitive with corn ethanol and cellulosic ethanol plants because of the short sweet sorghum harvest season combined with the limited storage potential for the crop. However, other researchers have considered sweet sorghum syrup as a substitute for corn as feedstock in corn ethanol plants during a sweet sorghum harvest window of about two months between August and October.[1] Corn ethanol plants would require some modification to accommodate the sorghum juice as a feedstock. The bagasse (the dry residue left after juice is extracted from the stalks) can be burned for energy to substitute for natural gas use in the plant over about half of the year. The economic feasibility of this

Richard Perrin and Lilyan Fulginiti are professors in the Department of Agricultural Economics at the University of Nebraska, Lincoln. Subir Bairagi is a postdoctoral fellow at the International Rice Research Institute in Los BaÃśos, Philippines. Ismail Dweikat is a professor in the Department of Agronomy and Horticulture at the University of Nebraska, Lincoln.
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[1] See, for example, Bennett and Anex (2009) and Wortmann and Regassa (2011), among others who have explored this possibility.

system in the Great Plains will depend on corn prices, sweet sorghum yields, the value of advanced biofuel RINs, and other factors. In this study we search for combinations of circumstances under which this technology may be economically feasible.

Sweet Sorghum RIN Values

The Energy Independence and Security Act of 2007 (EISA) established a renewable fuel standard known as RFS2, which specifies that mandated quantities of various renewable fuels must be blended into the motor fuel supply. Individual fuel blenders are obligated to blend their proportionate shares of these volumes (known as renewable volume requirements, or RVOs), and they must demonstrate annual compliance by submitting the appropriate number of Renewable Identification Numbers (RINs) for each category of fuel. A RIN is provided by the renewable fuel producers when a gallon of renewable fuel is sold to a blender.

Once issued, a RIN may be either surrendered to the EPA to demonstrate compliance or sold to another blender who would rather incur that expense than to purchase a gallon of renewable fuel. RINs thus attain a market value when exchanged among blenders, with demanders demonstrating a willingness to pay for a RIN rather than to purchase a gallon of renewable fuel and suppliers demonstrating a willingness to sell a RIN rather than to surrender it as evidence of compliance. Basically, the value of a RIN reflects the marginal cost to the blending industry of purchasing renewable fuel instead of gasoline.

But the RIN price story becomes much more complicated (see Irwin, 2015, 2016) because the RFS2 mandates minimum volumes for each of five nested categories of renewable fuels, each with its own RIN to ensure compliance. The categories are established primarily on the basis of the nature of the biomass used and the percentage reduction in life-cycle greenhouse gas (GHG) emissions relative to the petroleum substitute (gasoline or diesel). These categories, identified here by their RIN label, are:

- D7, cellulosic diesel, made from cellulosic feedstock, with 60% reduction GHGs;
- D3, other cellulosic biofuel, made from cellulosic feedstock, with 60% reduction in GHGs;
- D4, biomass diesel, made from biomass, with 50% reduction in GHGs;
- D5, advanced biofuel made from biomass with 50% reduction in GHGs (under which sweet sorghum ethanol will fall); and
- D6, renewable fuel with 20% reduction in GHGs (primarily ethanol made from starch, such as corn ethanol).

Figure 1 illustrates the nesting structure of the RIN categories. D7 is nested within D3, meaning that a gallon of cellulosic diesel can be used for compliance with cellulosic biofuel RVO (but *not* vice versa). D3 and D4 are nested within D5, meaning that any D7, D3, or D4 RIN can be used for compliance with the advanced biofuel RVO. Finally, all the other categories are nested within the D6 renewable fuel category. This means that any RIN can be used for compliance with the "renewable fuel" RVO, and thus the value of the D6 RIN (as generated by corn ethanol) must always have the lowest price among all RINs. Fuel from sugar cane syrup and sweet sorghum syrup are among those defined as "advanced biofuels," thus their D5 RIN price must always be higher than (or equal to) the D6 RIN (the "renewable fuel" category, to which corn ethanol is assigned). But, similarly, the D5 RIN must always be priced at least as low as the D3, D4, or D7 RINs because these three could be purchased to satisfy the D5 RVO.

Until January 1, 2017, biomass diesel producers almost continuously received a \$1.01/gal subsidy, bringing supply costs down to levels comparable to corn ethanol, and thus the value of the D4 and D5 RINs were not only equal to one another but also equal to the D6 corn ethanol RIN.

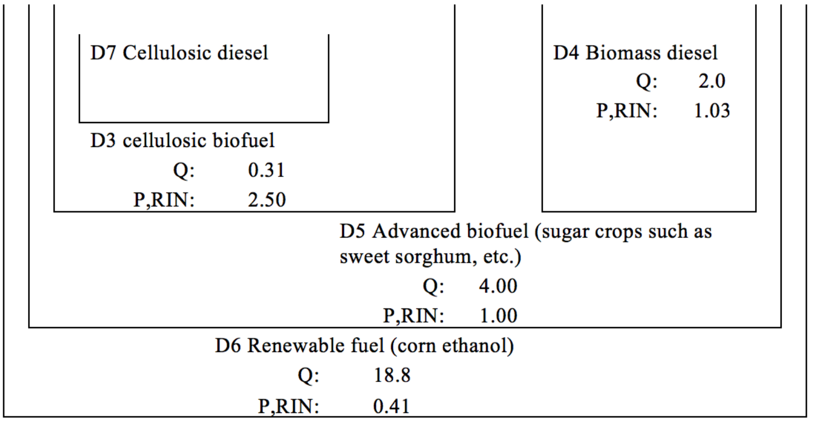

Figure 1. RFS2 Structure

Notes: Q is the RVO for 2017 (billion gal), P is the price per gallon as of May 2017.

The elimination of this biomass diesel subsidy freed this tight linkage between D5 and D6 RINs, and during the following few months the price of the D6 RIN drifted to \$0.35–\$0.70/gal, creating a spread between D5 and D6 RINs of about \$0.50/gal, falling to \$0.35/gal by mid-year. In theory, this spread should indicate that the cost of producing (or importing) D5 advanced biofuels such as sweet sorghum ethanol is \$0.50–\$0.35/gal higher than producing (or importing) D6 renewable fuels such as corn ethanol. Blenders are willing to pay this much more for sweet sorghum ethanol than for corn ethanol, creating an extra incentive for ethanol plants to substitute sweet sorghum syrup for corn grain. This spread may or may not continue (depending in no small part on sugar prices in Brazil) and it represents a major uncertainty for the decision to use sweet sorghum syrup or corn grain as feedstock in a corn ethanol plant. Our next task is to examine whether production costs using sweet sorghum as a feedstock are likely to be no more than \$0.35/gal higher than using corn grain as a feedstock.

Sweet Sorghum Production Costs in the Great Plains

Sweet sorghum is a row crop requiring production techniques very similar to those for corn. It is more tolerant to heat and drought than commercial corn crops in the Great Plains and shows good yields despite inconsistent response to fertilizer (Wortmann and Regassa, 2011). Thus, it may provide a more profitable crop for producers in this region than dryland corn.

Expected Sweet Sorghum Yields in the Great Plains

While it is relatively straightforward to budget the costs of producing sweet sorghum, the lack of information about yield expectations and the limited knowledge about harvesting and crushing equipment affects the accuracy of estimating feedstock costs per gallon of ethanol. Yields that Great Plains producers might reasonably expect to achieve are difficult to determine. Recent experimental results are scarce, and—for those that do exist—yields per land area have been measured and reported idiosyncratically (i.e., as fresh biomass weight, fresh stalk weight, dry stalk weight, or juice weight). Beyond that, different assumptions have been invoked to estimate the volume of ethanol that could be produced from any one of these measures. Wortmann and Regassa (2011) summarize a number of studies relevant to yield expectations for Great Plains farmers. Those studies show a range of yields from 36–140 tons of fresh biomass per hectare (14–57 tons/acre). The authors report that ethanol yields from such experiments generally range from 3,000–4,000 l/ha (320–425 gal/acre), though they also cite a yield as high as 6,000 l/ha. A set of multi-year, multi-site experiments in

Table 1. Base Assumptions for Great Plains Dryland Agriculture

Variable	Units	Symbol	Value
Price of standing sweet sorghum	$/ton	Ps	5.00
Price of corn	$/bu	Pc	3.50
Price of dried distillers grains	$/ton	Pd	95
D5–D6 RIN spread	$/gal	Pr	0.35
Cash rental rate for unirrigated cropland	$/acre	R	45
Yield of sweet sorghum	tons/acre	Ys	20
Yield of corn	bu/ac	Yc	65
Ethanol yield of sweet sorghum	gal/ton	ys	12
Ethanol yield of corn	gal/bu	yc	2.8

Table 2. Sweet Sorghum Production Budget (Yield of 20 Tons of Fresh Biomass per Acre)

Production Cost Items	$/acre	$/ton	$/gal
Land rent	45.00	2.25	0.188
Spray herbicide	7.00	0.35	0.029
Glyphosate 32 oz., 2,4-D 1.5pt	7.94	0.40	0.033
No-till planting, custom	17.58	0.88	0.073
Seed, 2.5 lbs. @ 6.00	15.00	0.75	0.063
No fertilizer	0.00	0.00	0.000
Spray herbicide	7.00	0.35	0.029
Herbicide, 2,4-D, 0.75pt @ $2	1.50	0.08	0.006
Total production cost	101.02	5.05	0.421

Nebraska (Wortmann et al., 2010) resulted in ranges of 27–104 Mg/ha of fresh *stalk* weight (3–12 tons/acre) and estimated ethanol yields of 967–4,133 l/ha (100–440 gal/acre). Yields have been shown to differ by site, by year, and by variety, but they are in general not responsive to nitrogen applications or to plant populations. Clearly, unknown yields would be a major issue of concern to both farm producers of sweet sorghum for ethanol and to the ethanol processor using the crop. We return to this issue later.

Enterprise Budgets

We take dryland corn production as the opportunity foregone if farmers were to produce sweet sorghum; for the ethanol plant, the opportunity cost of using sorghum juice is to continue to purchase corn grain during the two-month harvest window. To analyze the feasibility of the system, we begin with budgets for each of these enterprises. Table 1 lists the base values that we assume for a number of basic parameters, which will change as we consider the ranges of feasibility of the system. The sweet sorghum and corn production budget estimates (tables 2 and 3) are based on inputs described by Wortmann et al. (2010), custom farming rates from Wilson (2014), cash rental rates from Jansen and Wilson (2015), and University of Nebraska, Lincoln, crop budget estimates (Klein et al., 2015). Our base estimate sweet sorghum yield of 20 tons/acre (fresh basis) is based on Wortmann et al. (2010), and our corn yield estimate of 65 bu/acre is based on recent area yields as reported by the USDA National Agricultural Statistics Service (2017).

In table 4 we present partial budget information showing the costs and benefits that are affected by the decision whether to switch to seasonal sweet sorghum processing, expressed per gallon of ethanol produced. The budget for operating a grain ethanol plant using the normal corn grain feedstock is based on input requirements from a plant survey (Perrin, Fretes, and Sesmero, 2009), with prices updated. The sweet sorghum transport and processing cost estimates are based on engineering cost estimates developed by Bennett and Anex (2009) for their lowest-cost system (option 1: four-row self-propelled harvester with direct in-field loading into transport truck, ethanol

Table 3. Corn Production Budget (per Acre, No-Till, Dryland, 65 bu Yield)

	Custom Rate	Material	Total
Land rent			45
Custom no-till plant	20		20
Seed		29	29
Insecticide		19	19
Fertilizer (10-34-0)		20	20
Spray herbicide	7	54	61
Spray insecticide	7	5	12
Custom combine	30		30
Cart and haul	10		10
Dry grain (2 pts)	8		8
Total	82	127	254

Notes: Adapted from UNL Budgets 15 and 16, EC872, 2015.

Table 4. Per Gallon Cost of Corn versus Supplementary Sweet Sorghum as Alternative Ethanol Feedstocks

	Corn Feedstock $/gal	Sweet Sorghum $/gal
Harvest[a]		0.17
Transportation to plant[a]		0.30
Extra capital cost, crusher and boiler[a]		0.32
Operating cost[b]	0.31	0.31
Less by-product credit[c]	−0.31	−0.18
Net plant cost	0.00	0.92
Delivered feedstock price ($/bu, $/t)	3.50	5.00
Feedstock cost per gallon of ethanol	1.25	0.42
Total operating and feedstock cost	1.25	1.34
D5–D6 RIN spread		−0.35
Cost adj for RIN value		0.99

Notes: [a]Sweet sorghum estimates from Bennett and Anex (2009).
[b]Authors' estimates, assumed equal for the two feedstocks.
[c]See text.

plant 48 million gal/year capacity). In what follows we convert their cost components per Mg of fermentable sugar (FC) to costs per gallon based on an assumption of 140 gal/Mg FC.[2]

Bennett and Anex (2009) estimate the cost of harvest and transport at about $23/Mg FC and $42/Mg FC, respectively, or $0.17/gal and $0.30/gal of ethanol (first two rows of table 4). They further estimate that capital investments of about $30 million would be required to modify a typical grain ethanol plant for crushing sweet sorghum stalks and to modify the boiler to be able to burn the bagasse. They amortize these investments to obtain capital costs per Mg of FC at the scale of an ethanol plant with annual capacity of 48 million gallons per year, resulting in a 7% discount rate, for an amortized capital cost of $0.32/gal of ethanol. We estimate operating costs for both feedstocks at $0.31/gal, which we obtain by adjusting the $0.45/gal in Perrin, Fretes, and Sesmero (2009) down to $0.31/gal to account for a reduction in natural gas price from $7.20/MMBtu (1 MMBtu equals 1 million Btu) in their survey to the approximate current price of $2.00/MMBtu.

By-product credit for corn ethanol is for dried distillers grains (DDG), which is worth about $0.31/gal of ethanol produced at the current DDG price of $95/ton. Bennett and Anex (2009) estimate the value of the sweet sorghum bagasse by-product based on its energy value, which they

[2] Bennett and Anex (2009, p. 1598) assume 1.75 kg per FC/1 x 0.95 extraction efficiency, or about 140 gal/Mg FC.

estimated to be \$4, \$6, or \$8 per MJ (megajoule). This estimate requires a major adjustment, since the price of the natural gas that the bagasse would replace is only about \$2/MMBtu (1 MMBtu equals 1.05 MJ). Using the Bennett and Anex estimate of 19.75 MJ/Mg FC (equivalent to 0.14 MJ/gal of ethanol produced) at \$2/MJ provides an estimated value of \$0.18 per gallon of sweet sorghum ethanol produced, which we show as the by-product credit in table 4. This is the value of the bagasse in replacing natural gas budgeted in the operating cost, whether it is used during the sweet sorghum feedstock phase or the corn feedstock phase. (Bennett and Anex estimate the amount to be sufficient to supply process energy for the plant for 6 months.)

With these base assumptions, plus feedstock payments of \$3.50/bu for corn and \$5.30/ton of sweet sorghum fresh weight, we estimate that for the ethanol plant the net processing plus feedstock costs using sweet sorghum are higher than corn feedstock by about \$0.10/gal (=\$1.35–\$1.25). Thus, the RIN spread must be at least \$0.10/gal for the plant to break even by switching to sweet sorghum as a feedstock during the two-month harvest season. In the previous section, we noted that the RIN spread during the first half of 2017 was about \$0.35–\$0.50/gal.[3] Hence, we conclude that there is a reasonable case for asserting that this sweet sorghum ethanol pathway is economically feasible. We pursue this further in the analysis below.

Economic Feasibility of Seasonal Sweet Sorghum Syrup as Feedstock in Grain Ethanol Plants

For the pathway described here to be economically feasible, it must be feasible for both farmers and for the ethanol plant. Farmers must be able to earn as much net revenue per acre as they would from growing corn, which sets the minimum price they would be willing to accept (WTA) for a sweet sorghum contract. On the other hand, the maximum price the ethanol plant would be willing to pay (WTP) is the opportunity cost of continuing to use corn grain during the sweet sorghum harvest season. Below we consider WTA and WTP, then identify price and yield circumstances under which both the plant and farmers could benefit from the system. The distribution of such benefits would depend upon negotiations between farmers and the plant regarding the price to be paid per ton of fresh sweet sorghum standing in the field. We do not pursue that issue here.

Farmers' Willingness to Accept Sweet Sorghum Production

Above we have defined WTA as the minimum contract price that farmers would be willing to accept such that the expected net revenue per acre from sweet sorghum exceeds that from growing corn. We base our estimates of WTA contracts for standing sweet sorghum production on the base assumptions shown in tables 1, 3, and 4, which include expected yields of sweet sorghum at 20 tons/acre (240 gallons of ethanol per acre) and corn at 65 bu/acre, on land with rental rates at \$45/acre.[4]

The minimum contract price for sweet sorghum that would result in a net return per acre equal to or greater than that from corn can be expressed as follows:

$$P_sY_s - C_s \geq P_cY_c - C_c, \text{ or}$$
$$P_s \geq \left(\frac{Y_c}{Y_s}\right) P_c - \frac{1}{Y_s}\left(C_c - C_s\right), \tag{1}$$

where P_s is the contract price for standing sweet sorghum; P_c is the price of corn in \$/bu (from table 1, \$3.50/bu); Y_s is the yield of sweet sorghum biomass (from table 1, 20 tons/acre); Y_c is the yield

[3] Research by Knittel, Meiselman, and Stock (2015) indicates that 100% of RIN value is ultimately passed through to ethanol producers.

[4] The average sweet sorghum yield in High Plains experiments (Wortmann et al., 2010) was approximately 20 tons/acre. The University of Nebraska provides a budget for an expected yield of 90 bu/acre for dryland corn in this region, but the average nonirrigated corn yield in southwest Nebraska, 2010–2014, was 64 bu/acre. The average 2015 cash rental rate for nonirrigated land in that region was \$45/acre (University of Nebraska-Lincoln, 2015).

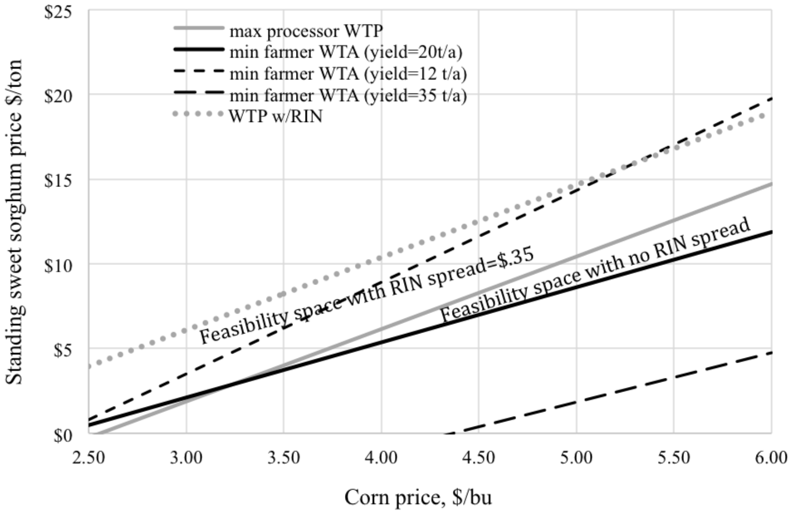

Figure 2. Minimum Willingness to Accept, Maximum Willingness to Pay, and Feasible Prices Space, With and Without RIN Spread of $0.35/gal

of corn (from table 1, 65 bu/acre); and C_c and C_s are the per acre costs of producing corn and an unharvested crop of sweet sorghum (from tables 2 and 3), $101/acre and $254/acre, respectively.

Evaluating equation (1) at our base assumptions, the minimum sweet sorghum contract price that would result in per acre revenue equal to corn (WTA) is $P_s = \$3.73$/ton. This WTA varies with the price of corn, a relationship shown in figure 2 as a solid black line. Producers should be willing to accept (WTA) sweet sorghum production at price combinations above this line because expected per acre net return from sweet sorghum production would exceed that from corn production. At the expected corn price of $3.50, the producers' minimum WTA price can be seen here to be $3.73/ton, whereas if corn price rose to $4.00/bu, the WTA would rise to about $5.10/ton.

In figure 3 we trace the minimum sweet sorghum yield, relative to corn yield, necessary for farmers to earn more per acre from sweet sorghum than from corn. To obtain this we solve equation (1) for sweet sorghum yield, Y_s, to obtain

(2) $$Y_s \geq \left(\frac{P_c}{P_s}\right) Y_c - \frac{1}{P_s}\left(C_c - C_s\right).$$

Evaluated at our base assumptions (including P_c=$3.50/bu, P_s=$5.00/ton[5] and corn yield at 65 bu/acre), equation (2) (and figure 3) indicates that only if $Y_S \leq 15$ tons/acre would sweet sorghum return more per acre than corn, whereas if corn yielded only 50 bu/acre a sweet sorghum yield of about 5 tons/acre would be sufficient to be more profitable, but if corn yield were 100 bu/acre, sweet sorghum yield would need to be 40 tons/acre to compete.

We emphasize that equation (2) defines the minimum breakeven sweet sorghum price that makes returns from sweet sorghum production equal to those from corn production. Even though row-crop production practices for sweet sorghum are similar to those of corn, farmers may have other reasons to be reticent to contract to produce a new crop, including the loss of historical corn acreage base related to other federal program benefits.

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[5] We chose $5.00/ton, which would provide approximately an even split of benefits between farmers and ethanol plants under our base assumptions, to be explained later. The split does not affect the viability of the pathway, only how benefits are divided.

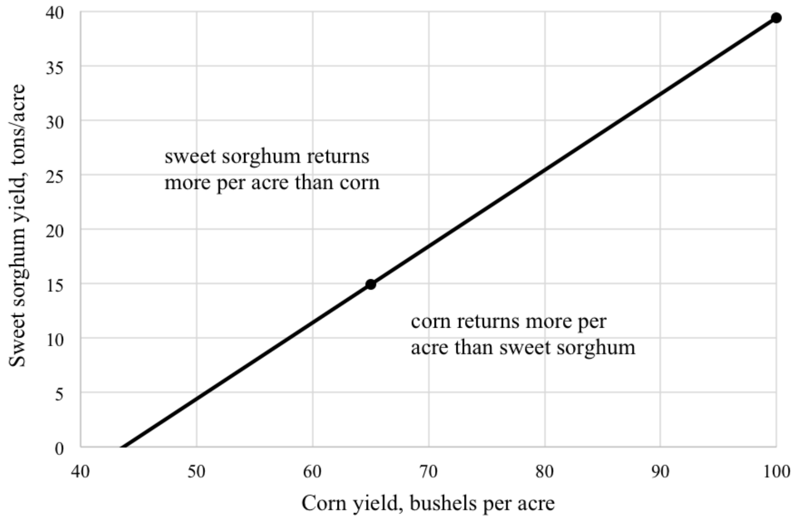

Figure 3. Minimum Sweet Sorghum Yield to Compete with a Corn Crop, vs Corn Yield, Given $P_s = \$5.00$/ton and $P_c = \$3.50$/bu

Ethanol Plants' Willingness to Pay for Sweet Sorghum

The maximum price an ethanol plant would be willing to pay (WTP) for sweet sorghum standing in the field as a substitute for corn grain feedstock is the amount they would save by using sweet sorghum instead of corn grain, determined as

$$\text{(3)} \qquad \frac{P_s}{y_s} + c_s - RIN < \frac{P_c}{y_c} + c_c, \text{ or } P_s < \left(\frac{y_s}{y_c}\right) P_c + (c_c - c_s + RIN)\, y_s,$$

where P_s is the price per ton of standing sweet sorghum; y_s is the yield of ethanol per ton of sweet sorghum (from table 1, 12 gal/ton); c_s is the net cost of harvesting, transporting, and processing sweet sorghum per gallon of ethanol produced (from table 4, \$0.92/gal); P_c is the price per bushel of corn purchased by the ethanol plant (from table 1, \$3.50/bu), y_c is the yield of ethanol per bushel of corn (from table 1, 2.8 gal/bu); c_c is the net cost of processing corn per gallon of ethanol produced (from table 4, \$0.00/gal); and RIN is the RIN price spread between D5 RIN and D6 RIN (base value \$0.35/gal).

Under these base assumptions, we calculate from equation (3) that plants' maximum WTP for sweet sorghum is \$8.23/ton. In figure 2 this is the value of the dotted gray line evaluated at the corn price of \$3.50. Without the benefit of the RIN spread, plants' WTP falls to \$4.03/ton, about \$0.30/gal higher than farmers are willing to accept, so the pathway is somewhat feasible even without the RIN spread.

Economic Feasibility Space

Figure 2 allows us to observe circumstances under which this sweet sorghum ethanol pathway is economically feasible (i.e., circumstances under which plants' WTP exceeds farmers' WTA). For example, when corn price is \$3.50/bu and RIN spread is \$0.35/gal, the dotted gray line indicates that \$8.23/ton is the maximum the plant could pay and still earn the same as when using corn grain as feedstock.[6] The solid black line indicates that the minimum price the farmer could accept for sorghum and still earn the same as with corn production is \$3.73/ton. Here there is a net benefit

[6] Transportation costs beyond the \$0.30/gal budgeted in table 4 will reduce this amount.

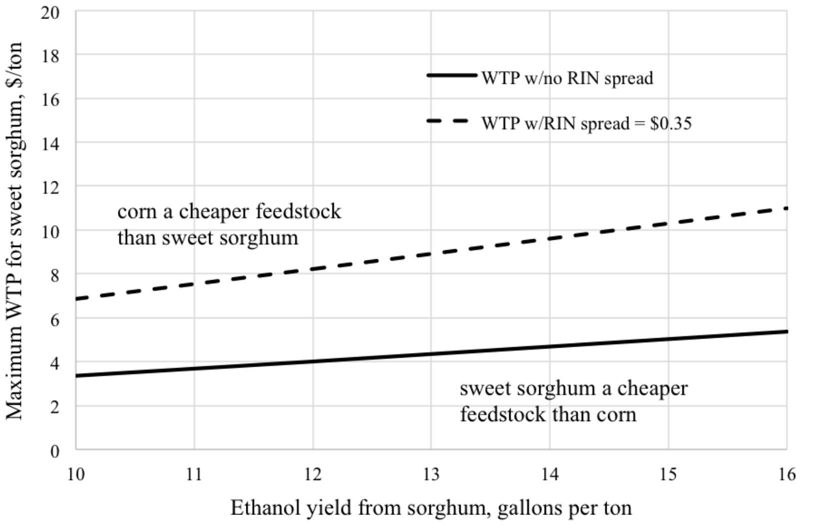

Figure 4. Maximum Price Processor Can Pay for Standing Sweet Sorghum (WTP) vs. Ethanol Yield

to this production pathway (including a RIN spread of $0.35/gal) of $8.23–$3.73 = $4.50/ton of sweet sorghum. At corn prices above $3.50, this benefit rises, reaching $18.94–$11.85 = $7.09/ton of sweet sorghum. On the other hand, with no RIN price spread, only if corn price exceeds $3.25/bu does the WTP line equal or exceed the WTA line. With corn prices of $3.25–$3.50/bu and no RIN spread, there appears to be a small benefit to the sweet sorghum system, but it is likely not sufficient to warrant the risky investments needed.

The effect of sorghum yields on this economic feasibility space can be observed by comparing the broken black lines with the gray lines: at a yield of 12 tons/acre the pathway is possibly feasible with a $0.35/gal RIN spread but not at all feasible with no spread. At a yield of 35 tons/acre (the lower dashed black line) the pathway is highly feasible at any corn price, even with no RIN spread. The division of benefits from the sweet sorghum pathway between farmers and plants would depend upon negotiations between them to determine the price the plant pays the farmers for sorghum (the corn price being exogenously given to them by market forces).

Another source of uncertainty is the yield of ethanol per ton of sweet sorghum. In figure 4 we illustrate how processors' WTP varies with ethanol yield from sweet sorghum, under base assumptions for other variables. For the base assumption of 12 gallons of ethanol per ton of fresh sweet sorghum (the median of results from the Nebraska trials) and the $0.35/gal RIN spread, the plants' WTP for sorghum is $8.22/ton, but this drops to $4.02/ton without the spread. If yields are as low as 10 gal/ton of sweet sorghum, WTP is only $6.85/ton, rising to $10.55/ton with yields at 16 gal/ton. All of these prices are above farmers' base WTA of $3.73/ton, indicating economic feasibility. The generally flat slope of the lines in figure 4 suggest that the ethanol yield per ton of sorghum is not a critical factor in determining the feasibility of this enterprise.

Economic Feasibility of Sweet Sorghum Feedstock for Existing Corn Ethanol Plants in the Great Plains

Several grain ethanol plants currently operate in the Great Plains: Bridgeport Ethanol in Bridgeport, NE; Mid-America AgriProducts in Madrid, NE; Midwest Renewable Energy in Sutherland, NE; Sterling Ethanol in Sterling, CO; Trenton AgriProducts in Trenton, NE; and Yuma Ethanol in Yuma, CO. The economic feasibility of the sweet sorghum pathway for these plants depends upon the

Table 5. Supply Radius Needed to Provide Sweet Sorghum Feedstock at Various Ethanol Plants

Plant Location	County	Capacity (mgy)	Crop Acres Needed	Crop Density	Supply Radius (Miles)	Extra Transportation Cost per Ton
Bridgeport, NE	Morrill	54	37,500	0.0197	53.6	1.40
Madrid, NE	Perkins	44	30,556	0.2936	12.5	0.08
Sutherland, NE	Lincoln	28	19,444	0.0413	26.7	0.53
Sterling, CO	Logan	42	29,167	0.1313	18.3	0.27
Trenton, NE	Hitchcock	40	27,778	0.3175	11.5	0.05
Yuma, CO	Yuma	40	27,778	0.1097	19.5	0.31

likely radius from which contracting producers might be drawn. We have budgeted the equivalent of $0.30/gal to transport sweet sorghum stalks from the farm to the plant. This cost may be higher if potential sweet sorghum density requires transportation over more than an average of about 10 miles in order to meet the plant's capacity.

In table 5 we examine the feasibility of the sweet sorghum system for each of these plants. We estimate the necessary radius to supply two months of production, based on an arbitrary assumption that one-third of the current non-irrigated corn and wheat acreage in the surrounding area could be contracted to produce standing sorghum. Only the plants at Madrid, NE, and Trenton, NE appear to have supply regions of approximately 10 miles or less. The average transportation cost per ton (or per gallon) rises in direct proportion to the supply radius (Perrin et al., 2012). Extra transportation costs above the 10-mile radius are shown in the last column of table 5. We calculate that the Trenton and Madrid plants could have production radiuses close to the 10 miles that we have budgeted, thus would be most likely to find the sweet sorghum pathway feasible. The extra transportation costs for the Bridgeport and Sutherland plants would probably exceed even the $0.38/gal benefit under a RIN spread of $0.35/gal, while the two Colorado plants might be able to arrange supply contracts at a feasible cost. However, a vigorous effort to obtain contracts with farmers within 10 miles or so might make the pathway feasible for any of these plants.

Conclusions

This research attempts to identify the circumstances under which a sweet sorghum ethanol production pathway in the Great Plains would be economically feasible, with special attention to the role of RIN prices. The pathway consists of substituting sweet sorghum juice for corn grain as feedstock in grain ethanol plants, during the two-month sweet sorghum harvest season. The system we consider is one in which farmers contract with an ethanol plant to produce a non-irrigated crop of sweet sorghum, standing in the field unharvested, which the plant then harvests, transports and processes into ethanol and bagasse fuel over the two-month harvest window. Ethanol produced with this pathway, which includes using the bagasse for fuel, should qualify as an advanced biofuel with D5 RIN credits, rather than the lower-value D6 credits generated by using corn as the ethanol feedstock. Thus the price spread between D6 and D5 RINS has an important impact on the economic feasibility of this pathway.

Our base assumptions include dryland sweet sorghum yields of 20 tons fresh weight per acre, corn yielding 65 bu/acre as the alternative crop; capital investments of about $30 million for transportation, handling and extra milling equipment; corn priced at $3.50/bu and distillers grains (DDG) priced at $95/ton. Under these base assumptions, we find that the pathway is close to breakeven, a budgeted benefit equivalent to $0.03 per gallon of sweet sorghum ethanol, even with no RIN spread. At recent (mid-2017) RIN price spreads of $0.35/gal, the benefit rises to $0.38/gal, a significant economic opportunity, equivalent to $90/acre in excess of earnings compared to a corn crop.

The distribution of these estimated benefits between farmers and the ethanol plants would depend upon the price negotiated to be paid for the sorghum standing in the field. With a RIN spread of $0.35/gal, we estimate that the plants' maximum WTP is about $8.23/ton, while farmers' minimum WTA is about $3.73/ton, implying a margin of about $4.50 to be negotiated. With no RIN spread, the WTP falls to $4.03, leaving a margin of only $0.30/ton to be negotiated. This narrow margin is probably too small to entice the investments to be made.

Our analysis shows that while the level of ethanol yield from fresh sorghum stalks does not appear to have an impact on feasibility, the yield per acre of dryland sweet sorghum relative to dryland corn certainly does. At corn yields of 65 bu/acre typical of the region, sweet sorghum yields of at least 15 tons of fresh stalks per acre are needed for sweet sorghum to be more profitable. For corn yields of 80 bu/acre, sweet sorghum yield must increase to about 25 tons/acre to remain more profitable (or, equivalently, gallons of ethanol per acre of sweet sorghum must rise from 240 to 400).

Based on our speculation about the geographic density of cropland and farmer participation, we estimate that two of the six existing plants in this region would find this pathway to be economically feasible even with no RIN spread. We estimate that two more plants would find it feasible with a RIN spread of $0.35/gal, while it appears that for the remaining two plants, low production density would make transportation costs too high unless RIN spreads were substantially higher.

This study demonstrates the effectiveness of EISA's RIN pricing mechanism in potentially stimulating new sources of renewable biofuels. At the D6-D5 RIN spreads exceeding $0.35/gal during the first half of 2017, the sweet sorghum ethanol pathway described would provide a clear potential for providing new sources of income for some ethanol plants and dryland farmers in the dry areas of the Great Plains. Without benefit of a RIN spread, the pathway might still prove economically attractive for some plants. Uncertainty about the future path of the RIN spread, however, diminishes the incentive for others.

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