Can Sweet Sorghum and Sweetpotato Ethanol Contribute to Self-Sufficiency of Small Farms?

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Introduction

US biofuel mandates require production of 36 billion gallons of ethanol fuel annually by 2022, more than triple the 11 billion gallons produced in 2009 (HR 6, 2007; RFA 2009). Almost all ethanol fuel produced today is made by fermenting and distilling sugars derived from corn starch, using a process that reduces greenhouse gas (GHG) emissions, relative to gasoline, by about 13% (Farrell et al., 2006). Mandates require that most ethanol produced in 2022 will use advanced processes that depend on feedstocks other than corn starch and reduce GHG emissions by at least 50%, relative to gasoline (HR 6, 2007).

Combustion of 36 billion gallons of ethanol will yield about 3 quadrillion BTU of usable energy, roughly 3% of the energy – or 7% of the petroleum-derived energy – currently used in the USA each year. Current ethanol production methods are less petroleum-intensive than gasoline, but draw roughly three-quarters of the energy released during ethanol combustion from other non-renewable sources, such as natural gas and coal (Farrell et al., 2006). Ethanol derived from corn starch could therefore be considered about one-quarter renewable. Advanced processes should increase the renewable proportion.

Achieving ethanol production targets for 2022 will do little to reduce US dependence on non-renewable energy sources, but will have dramatic impacts on the agricultural landscape. Ethanol production demanded about 30% of the US corn yield in 2009. This proportion will grow slightly over the next decade, to about 35%. Most of the remaining growth in demand for ethanol feedstocks will come from increased acreage devoted to cellulosic crops, such as switchgrass; and non-corn crops that produce starches and sugars, such as sweet potato or sweet sorghum.

Although ethanol has little potential to substantially reduce US fossil fuel use, it could already entirely eliminate petroleum consumption by US farms. Between 1978 and 2002, petroleum consumption by US farms fell by 39%, to 0.6 quadrillion BTU (Miranowski, 2005). This represents one-fifth of the energy released through combustion of corn-based ethanol in 2009. Replacing fossil fuels with renewable fuel on US farms is achievable, and may enhance food security in the event of a petroleum crisis.

Ethanol-driven demand for corn has chiefly benefited large Midwestern farms. About 16% of farms grow corn, and these farms tend to be 80% larger than average (USDA, 2008). Most ethanol is produced in large refineries that require hundreds of thousands of acres of corn to run at capacity (RFA 2009). Ethanol refineries are currently concentrated in the Midwestern Corn Belt (RFA 2009).

The argument for small-scale, decentralized ethanol processing is stronger for advanced ethanol than for conventional corn-based ethanol. Feedstocks proposed for advanced production tend to be bulkier than corn grain, and less amenable to long-distance hauling. Attempts to haul advanced feedstocks to large centralized ethanol refineries could compromise the lifecycle GHG and renewable energy advantages otherwise associated with their use. Advanced ethanol production may offer greater opportunities for small farmers.

Other potential advantages to small-scale, decentralized ethanol processing include:

- Opportunities to promote biodiversity by using a more diverse set of feedstocks;
- Opportunities to promote food security and food system resilience by ensuring that geographically diverse farms have access to locally-produced renewable fuel for food production;
- Opportunities to promote resource cycling by keeping nutritious byproducts of ethanol production close to their farm source, where they can be returned to farms as feed or fertilizer;
- Opportunities to produce feedstocks on small farms, which tend to use land more efficiently than large farms;
- Opportunities to reduce farm input needs through promotion of regionally-appropriate, low-input feedstock crops;
- Opportunities for more equitable distribution of wealth, and greater retention of wealth, by rural communities.

The opportunities associated with small-scale ethanol production suggest potential advantages in terms of economic, social, and environmental sustainability. Howard and Bringezu (2009) argue that small-scale biofuel production offers social and environmental benefits, but liabilities exceed benefits at larger scales.

Synthesis of pesticides and fertilizers – particularly nitrogen fertilizer – represents the largest component of indirect farm energy use in the US, accounting for about one-third of total farm energy use (Miranowski, 2005). Producing biofuel feedstocks without depending on synthetic pesticides or fertilizers could dramatically improve the lifecycle energy and GHG balance of biofuels. A recent report from the United Nations Food and Agriculture Organization (Zeisemer, 2007) suggests that:

> *Because of its reduced energy inputs, organic agriculture is the ideal production method for biofuels. […] As the aim of biofuels is to reduce dependency on nonrenewable energy sources and to mitigate environmental damage of fossil fuel emissions, organic production of biofuels furthers these goals in a way that conventional agriculture does not.*

In 2008 we began a four-year study to assess effects of biofuel feedstock production scale on land, labor, and energy use efficiency on small organic farms in Kentucky. We evaluated four feedstock crops: corn, sweet potato, sweet sorghum, and soybean. Sweet potato and sweet sorghum are both potential alternatives to corn grain; rich in carbohydrates and suitable for fermentation into ethanol. We hypothesized that these crops would be better adapted to low-input production on small farms than corn, and could be strong candidates for decentralized advanced ethanol production. Here we report preliminary results from the first two years of the four-year study.

Methods

The study was conducted on certified organic land at the Kentucky State University Research Farm that had been in alfalfa for three years previous.

Crops were grown at three scales, replicated four times in a randomized complete block design:

- Biointensive plots measured 11 x 20 ft. (5.1×10^{-3} ac) and were managed entirely with hand tools according to Jeavons (2002);
- Market garden plots measured 24 x 60 ft. (3.3×10^{-2} ac) and were managed with a combination of hand tools and walk-behind tractors with appropriate implements;
- Small farm plots measured 72 x 125 ft. (0.21 ac) and were managed with a combination of hand tools, walk-behind tractors, and conventional 4-wheeled tractors with appropriate implements.

Plots were evenly divided into four strips, which were randomly assigned to food and biofuel varieties of corn, sweet potato, sweet sorghum, or soybean, and planted in May, 2008. Following harvest, all plots were seeded to a winter cover crop mixture of winter rye and hairy vetch in late October, which was incorporated at vetch flowering in late April. Crops were rotated in subsequent years so that corn followed soybean, which followed sweet sorghum, which followed sweet potato, which followed corn.

The following data were collected for each plot for the duration of each year:

- Time and intensity of human labor expended;
- Volume of gasoline and diesel fuel used by machinery; and
- Crop yield. Here we report yields of biofuel varieties of corn (var. 56M30), sweet sorghum (var. 'M81E) and sweetpotato (var. 'Beauregard') only, since these are the most suitable ethanol feedstocks among the crops tested.

Metabolic energy associated with human labor was estimated using Metabolic Equivalent of Task (MET) index values of 2.5 for light work (e.g. driving a tractor), 4.0 for moderate work (e.g. hoeing or operating a walk-behind tractor), and 8.0 for intense work (e.g. deep cultivation with a spading fork or hand harvest of sweet potatoes). MET values were converted to energy values at 5 kJ per MET minute (Schwarz et al., 2006). Fossil energy density values of 32 MJ L^{-1} and 36 MJ L^{-1} were used for gasoline and diesel fuel, respectively (USDOE-ANL, 2009). Potential ethanol yield was estimated at 350 L Mg^{-1} (85 gallons per ton) for corn grain, 58 L Mg^{-1} (14 gallons per ton) for sweet sorghum cane, and 167 L Mg^{-1} (40 gallons per ton) for sweet potato tubers (Mathewson 1980).

Results

Biointensive plots used the most labor per unit area in both years, and small farm plots used the least (Table 1). An effect of farm scale on energy use was observed in 2009 only, when small farm plots used the most energy per unit area and biointensive plots used the least (Table 1). Metabolic energy accounted for all of the energy used at the biointensive scale, but only 19 and 8% of energy consumed at the market garden and small farm scales, respectively.

Corn and sweet sorghum yields were higher during the cool, wet summer of 2009 than the hot, dry summer of

2008; but sweetpotato yields were lower in 2009 (Table 2). Sweet sorghum gave the highest theoretical ethanol yield among the crops tested in both years (Table 3). Theoretical ethanol yield was similar for corn and sweetpotato in 2008, but sweetpotato gave the lowest theoretical ethanol yield in 2009 (Table 3).

Labor and energy use efficiencies in 2009 were double those in 2008 (Table 4). The effect of farm scale on labor use efficiency was similar between years, but the effect on energy use efficiency was not (Table 4).

Table 1. Labor and energy use at three organic ethanol feedstock production scales in 2008 and 2009. Energy use includes energy released by combustion of gasoline and diesel fuels in internal combustion engines and energy released by human metabolism during farm labor.

	Labor use (min m^{-2}) ± S.E.		Energy use (MJ m^{-2}) ± S.E.	
Farm scale	**2008**	**2009**	**2008**	**2009**
Biointensive	26.3 ± 1.6 a	16.76 ± 1.49 a	0.81 ± 0.11 a	0.46 ± 0.04 c
Market garden	7.8 ± 0.2 b	3.27 ± 0.08 b	0.77 ± 0.02 a	0.52 ± 0.02 b
Small farm	3.7 ± 0.1 c	2.05 ± 0.03 c	0.80 ± 0.05 a	0.65 ± 0.01 a

Table 2. Yield of corn grain, sweet sorghum cane (2008) and juice (2009), and sweetpotato tubers grown organically at three production scales in 2008 and 2009.

	Corn grain yield (kg m^{-2}) ± S.E.		Sweet sorghum yield (kg m^{-2}) ± S.E.		Sweetpotato tuber yield (kg m^{-2}) ± S.E.	
Farm scale	**2008**	**2009**	**2008 (cane)**	**2009 (juice)**	**2008**	**2009**
Biointensive	0.38 ± 0.03	0.67 ± 0.02	1.6 ± 0.7	1.85 ± 0.15	1.1 ± 0.3	0.88 ± 0.28
Market garden	0.57 ± 0.01	0.90 ± 0.10	4.2 ± 0.6	1.56 ± 0.38	1.2 ± 0.1	0.50 ± 0.09
Small farm	0.67 ± 0.04	0.71 ± 0.12	7.2 ± 0.4	0.80 ± 0.08	1.4 ± 0.1	0.69 ± 0.14

Table 3. Theoretical ethanol yield from corn, sweet sorghum, and sweetpotato grown organically at three production scales in 2008 and 2009.

	Theoretical ethanol yield (L m^{-2})								
	Corn		**Sweet sorghum**		**Sweetpotato**		**All feedstocks**		
Farm scale	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**	**All**
Biointensive	0.13	0.23	0.09	0.91	0.18	0.15	0.14	0.43	0.28
Market garden	0.20	0.31	0.24	0.77	0.20	0.08	0.21	0.39	0.30
Small farm	0.23	0.25	0.42	0.40	0.24	0.12	0.30	0.25	0.27
All scales	0.19	0.27	0.25	0.69	0.21	0.12	0.22	0.36	0.29
Both years	0.23		0.47		0.16		0.29		

Table 4. Labor and energy efficiency of organic ethanol feedstock production at three scales in 2008 and 2009. Respective efficiencies are measured as theoretical ethanol yield per minute of labor and per MJ of energy invested in feedstock production. Labor and energy used to process ethanol is not included.

	Labor efficiency (mL min^{-1})		Energy efficiency (mL MJ^{-1})	
Farm scale	**2008**	**2009**	**2008**	**2009**
Biointensive	5	26	173	935
Market garden	27	119	273	750
Small farm	81	122	375	385
All scales	38	89	274	690

Discussion

We observed different effects of scale on land, labor and energy efficiency of ethanol feedstock production between 2008 and 2009. The first year was unusually dry for the region; the second was unusually cool and wet. Other differences between years included poor crop establishment at the biointensive and market garden scales in 2008, and greater sweetpotato plant density in 2008 than 2009. These year-to-year differences emphasize the need to continue the study for several seasons to identify consistent trends and draw more rigorous conclusions. We plan to repeat this study in 2010 and 2011.

The national average ethanol yield from corn feedstock was 0.40 and 0.43 L m^{-2} in 2008 and 2009, respectively (RFA, 2009). Our small scale organic corn plots did not approach this theoretical yield in either year. Sweet sorghum consistently performed better than corn in our small scale organic plots, demonstrating the potential to generate substantially more ethanol per unit land area without resorting to high input production.

Since sweet sorghum cane is a bulkier and more perishable feedstock than corn grain, it is better suited to decentralized processing systems. Sweet sorghum juice extraction can occur on farm to reduce hauling costs. Sweet sorghum juice is approximately 20% sugar, making it ideal for direct fermentation.

It is unclear whether relying on more human labor to offset machinery use at small production scales increases energy efficiency. Labor efficiency was highest at the small farm scale and lowest at the biointensive scale in both years, but the biointensive scale only showed greater energy efficiency in 2009 (Table 4).

Current farm wages and ethanol prices in North America do not justify small-scale production of organic ethanol feedstocks, even if an energy efficiency advantage is observed. Ethanol prices in 2007-2010 have fluctuated around \$0.5 L^{-1} (\$2/gal), and average farm labor compensation is around \$12 hr^{-1} (TFC, 2010; Edwards and Sletten 2006), so any ethanol production rate below 400 mL min^{-1}, including growing and processing the crop, is uneconomical. The labor efficiency observed for crop production alone did not approach this threshold in either year (Table 4). The crops would have far greater value as organic food or feed than as ethanol feedstocks. A farmer's decision to dedicate a portion of small-scale organic crop yield to on-farm ethanol production might be justified as a means of promoting self-sufficiency, resource cycling, or use of waste products, but ethanol feedstock production would be a poor economic choice as a principal means of income for the small organic farmer.

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