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Energy Research

Farm Energy Production and Use Between Two Iowa Cropping Systems

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http://bit.ly/pfi_fieldcrops
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In a Nutshell

- Energy use in agriculture varies across cropping systems.
- This project explores the differences in energy use between two practical Midwest cropping systems.
- Diverse cropping systems, those with three or more crops, use a fraction of the energy inputs as compared to continuous corn.
- Dordt College established two farming system treatments in 2008: continuous corn (CC) versus a Gateway to Sustainability rotation (G2S) including corn, soybean, and oats with an under-seeding of red clover.
- PFI staff used the data to create a fossil fuel flow chart of the energy used to grow the different treatments.
- The G2S system is more efficient and can achieve similar yields per acre as the CC system.

Project Timeline:
September 2008 to September 2012

Background

Energy use in agriculture varies across cropping systems. This project explores the differences in energy use between two practical Midwest cropping systems; calculating energy needed to grow, harvest, and process crops into biofuels, and ultimately the net biofuel and fossil energy ratio.

Diverse cropping systems, those with three or more crops, use a fraction of the energy inputs as compared to continuous corn. Klepper et al. (1977) compared 14 Midwest organic farms with similar farms not using organic practices and found that the organic farms produced corn for 36% of the energy inputs used on the conventional farms. Nitrogen fertilizer is the greatest single energy input in corn production. In the Klepper et al. study, all farms whether organic or not, kept livestock and applied manure. Thirty years later, these two types of farming have diverged. Many conventional row crop operations do not have access to manure, and N fertilizer rates have increased.

The energy footprint of agriculture is a top priority for PFI members and has often been the focus of research and demonstration projects. Practical Farmers of Iowa (PFI) field days and workshops in 1992-1993 (LNC92-044) showed that farmer cooperators saved the energy equivalent to 12 gallons of diesel per acre by reducing nitrogen fertilizer by 50 lbs/A. To follow up on those initial on-farm demonstrations PFI partnered with Dordt College in NW IA to compare these systems in a controlled, side-by-side experiment.

Method

Dordt College established two farming system treatments in 2008: continuous corn (CC) versus a Gateway to Sustainability rotation (G2S) including corn, soybean, and oats with an under-seeding of red clover. Dordt College documented all field operations for planting and harvesting, the inputs applied to each treatment, and harvested yields (corrected for moisture content).

PFI staff used the data to create a fossil fuel flow chart of the energy used to grow the different treatments at Dordt College. Then PFI staff conducted a literature review and used published values to calculate the amount of energy needed to process the corn from both systems into ethanol and the soybeans from the G2S system into bio-diesel. The energy used to produce each of the crops was calculated from the diesel equivalents; organized into pre-harvest machinery, nitrogen inputs, and harvest machinery—estimated from Iowa State University Extension publication PM709. Published values were also used to estimate the amount of renewable energy produced and the heating equivalent, as if the products were burned instead of a bio-fuel.

Note: Yields were adjusted to accommodate the difference in rotation length. Since the G2S system is a three-year rotation, the corn, soybeans and oat/red clover crops is each only a third of the total area each year. In contrast, continuous corn is 100% of the total area each year. Therefore, 100% of the continuous-corn plot was assigned as the effective-area, while only 33.3% of each G2S component was assigned as the effective-area. No bio-fuel product was estimated for the oat/red clover part of the rotation; therefore 33.3% of the G2S rotation was assigned a zero for the calculation.

Two separate equations were used to summarize and report the final data results (**Box 1**).

Energy Efficiency is a ratio of the output energy to the input energy, while the *Land Efficiency* is the netted amount of energy per area of land. To understand how efficient the cropping systems were in their production of energy per acre we used both equations to ultimately determine which systems were more efficient.

Box 1

The Energy Efficiency value is a dimensionless ratio of the amount of energy returned as either ethanol or bio-diesel for each unit of energy put into the system, specifically in the processing, planting and harvesting of the crop. The Land Efficiency value is reported in mega-BTUs/Acre. This value is the NET energy produced per acre.

Equation 1

$$\text{Energy efficiency} = \frac{\text{Total biofuel energy output}}{\text{Total energy input}}$$

where:
Total Energy Input = Farm Energy Cost of Production + Biofuel Processing Energy

Equation 2

$$\text{Land use efficiency} = \text{Biofuel Energy Output} - \text{Farm Energy Cost of Production}$$

where:
Biofuel Energy Output = Total Biofuel Energy Output – Biofuel Processing Energy

Data Analysis

Data were analyzed using JMP Pro 10 (SAS Institute Inc., Cary, NC) and yield comparisons employ least squares means for accuracy. Comparisons of means were analyzed using the Tukey Honestly Significant Difference. Statistical significance is determined at α=0.05 level.

Results and Discussion

Biofuel

Based on the Energy Efficiency equation the G2S system in 2009 and 2011 was significantly more efficient than the G2S in 2010 (**Table 1**). The G2S system was more energy efficient than CC in all years. The G2S system yielded more energy across years, 36%, 30% and 38% respectively, for every fossil fuel BTU expended to plant, harvest and process the crops as compared to the CC system. However it is important to consider the total amount of energy that the different farming systems produced per acre. Using the Land Efficiency equation the CC treatment yielded significantly more energy per acre (9.49 M-BTUs/A) in 2010 than any other treatment in any other year. However, in two years out of three the CC and G2S farming systems produced similar amounts of total energy per acre. The G2S treatment in 2009 yielded the least amount of total energy per acre at 6.02 MBTUs/A. The CC treatment in 2009 and the G2S in 2010 yielded were statistically similar. Both farming system treatments were similar in 2011.

Taking both equations together, the G2S farming system is not only more efficient in the amount of energy it takes to produce the resulting energy commodity but also total production of energy per acre was similar to the CC farming system two out of three years.

Heat Energy

The heat energy equivalent was also calculated to demonstrate the amount of energy produced if the corn and soybean grains harvested from the cropground were burned instead of processed into biofuel. The magnitude of energy produced is much greater than when turning the crops into a liquid biofuel. Based on the Energy Efficiency equation in 2010 the G2S yielded the greatest amount of heat energy for every M-BTU used in the system (**Table 2**). The G2S system in 2011 and 2009 were statistically different and less than in 2010 — but significantly greater than all years in the CC system. All years of the CC system were statistically similar and averaged 15.2 M-BTU/M-BTU.

Table 1

Biofuel Energy Produced Per BTU and Per Acre

	ENERGY EFFICIENCY (M-BTU/M-BTU)		LAND EFFICIENCY (M-BTUs/A)	
	Continuous Corn	**Gateway to Sustainability**	**Continuous Corn**	**Gateway to Sustainability**
2009	1.29 CD	1.77 A	7.92 B	6.02 C
2010	1.32 C	1.72 B	9.49 A	7.32 B
2011	1.28 D	1.76 A	7.07 BC	7.10 BC

Table 2

Biofuel Energy Produced Per BTU and Per Acre

	ENERGY EFFICIENCY (M-BTU/M-BTU)		LAND EFFICIENCY (M-BTUs/A)	
	Continuous Corn	**Gateway to Sustainability**	**Continuous Corn**	**Gateway to Sustainability**
2009	14.9 D	68.0 C	56.8 B	32.0 D
2010	16.8 D	96.5 A	64.9 A	45.7 C
2011	13.8 D	89.6 B	52.6 B	41.5 C

*Means with similar letters are not statistically significant.

Comparing the yearly averages of the two systems, the G2S yielded 5.5 times more heat energy for every M-BTU expended to plant and harvest the crops as the CC system. However based on the Land Efficiency equation the CC system in 2010 yielded significantly more than the CC 2009 and 2011. The G2S system in 2010 and 2011 yielded statistically more heat energy than in 2009. The annual average of the CC system yielded 1.3 times more heat energy per acre than the G2S.

The energy to grow the three-year G2S rotation was significantly lower than the energy needed to grow the CC treatment (**Figure 1**).

Our study confirms that nitrogen fertilizer is the largest amount of energy expended in either of these cropping treatments (**Figure 2**). In the G2S rotation no synthetic fertilizer nitrogen was applied to the plots during the rotation. All nitrogen was grown on the farm and came from the red clover. In this experiment adding nitrogen-fixing legumes to the rotation drastically reduced the needed energy to grow, maintain and harvest the crops.

Conclusions

When considering both the Energy and Land Efficiency calculations together, the G2S requires less energy input (i.e., BTUs per acre) to convert energy from a crop to a biofuel. The G2S system is more efficient and for biofuel production can achieve similar yields per acre as the CC system. Additionally even though the CC system produces more heat energy per acre it requires 5.5 times more energy to create heat energy. In order to draw an appropriate conclusion, the analysis must include the economics and the CO_2 emissions produced by the two different cropping systems. This "expanded analysis" would be an excellent opportunity for future funding.

Figure 1

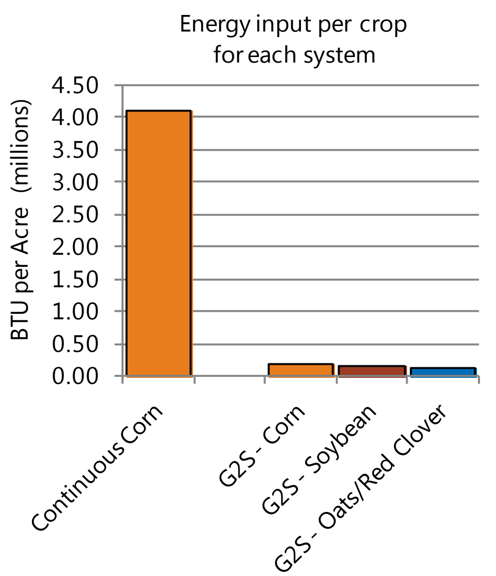
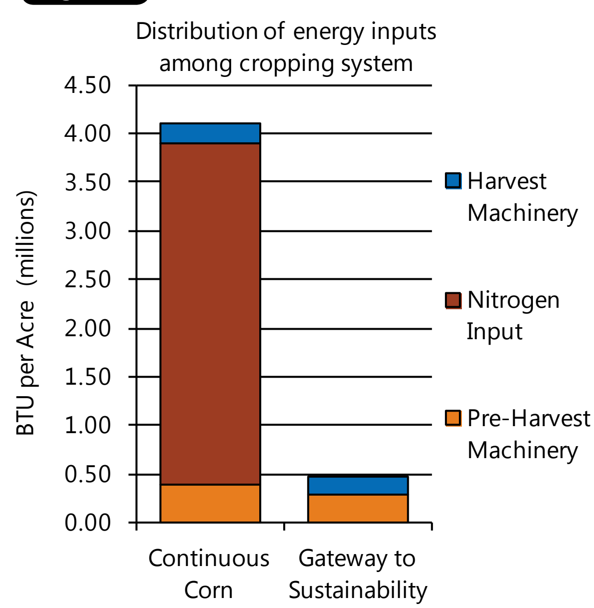


Figure 2



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PFI Cooperators' Program

PFI's Cooperators' Program gives farmers practical answers to questions they have about on-farm challenges through research, record-keeping, and demonstration projects. The Cooperators' Program began in 1987 with farmers looking to save money through more judicious use of inputs.