Economics and Energy of Ethanol Production from Alfalfa, Corn, and Switchgrass in the Upper Midwest

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Which crop is the best choice for ethanol production? It depends on the ultimate goal and a series of trade offs (Table 1). While corn currently is the “king” of ethanol production, alfalfa could be a good “queen” to corn for a variety of reasons. Switchgrass, too, has its place. How do these three crops compare?

In the United States, corn-based ethanol clearly is leading the way in biofuel production. However, corn grain alone cannot meet the U.S. government’s goal of replacing 30 percent of gasoline use by 2030.

Corn production requires fairly heavy nitrogen (N) fertilizer applications that can lead to N leaching and degradation of water resources. Intensive soil tillage practices often used in corn production can lead to significant soil erosion and associated environmental impacts. So while corn production clearly represents a significant energy source, its environmental impacts raise concerns about the long-term sustainability of continuous corn systems for bioenergy generation.

Table 1. *Comparison of three cropping systems for ethanol production with different goals in mind*

Goal	Maximize Farm Profit		Minimize Energy Used		Maximize Ethanol Production		Maximize Energy Efficiency		Soil & Water Conservation & Quality	
Crop Rotation	Farm production costs	Potential farm profit	On-farm energy used	Energy to convert to ethanol	Energy output in ethanol	Net energy produced (output minus input)	Net energy efficiency (output per input)	Byproduct energy output	Soil erosion	Nitrogen leaching
continuous corn	least desirable	most desirable	least desirable	least desirable	most desirable	most desirable	least desirable	most desirable	least desirable	least desirable
alfalfa/corn rotation (1 Establish, 2, 3, 4)	medium	medium	medium	medium	medium	medium	medium	medium	medium	most desirable
switch grass	most desirable	least desirable	most desirable	most desirable	least desirable	least desirable	most desirable	least desirable	most desirable	medium

Reducing the N fertilizer pollution and soil erosion of corn production would make it a much more sustainable source of ethanol. This can be accomplished by rotating a perennial legume like alfalfa into a continuous corn cropping system. In an alfalfa-corn rotation, ethanol could also be produced from the cellulosic biomass of alfalfa and corn stover as well as the corn grain.

While switchgrass is a widely considered feedstock option for future cellulosic ethanol production, alfalfa has a number of characteristics that make it a stronger candidate.

- Alfalfa is currently grown on 20+ million acres and is grown in almost every state in the country.
- Alfalfa averages 3.5 tons/ac of dry matter each year.
- The technology and machinery for cultivating, harvesting, and storing alfalfa is well established and widely available.
- Farmers are very familiar with the production of alfalfa.

Furthermore, there is also a well-developed industry for alfalfa cultivar development and seed production, processing, and distribution. These characteristics are not currently applicable for widespread switchgrass production.

The economic and environmental analysis...

To compare the advantages and disadvantages of different cropping systems for ethanol production, three rotations were evaluated:

- continuous corn for four years
- an alfalfa-corn rotation (two years alfalfa, two years corn)[a]
- continuous switchgrass for four years

For each crop system, both “normal” and “high” crop yield scenarios were assessed. It was assumed alfalfa hay harvested from a farm would be sold to a separation facility that would in turn sell alfalfa leaf meal to farms and alfalfa stems to an ethanol facility. To have some estimate of potential profits to a farmer across entire crop systems, low, medium, and high commodity price scenarios were considered. Analyses to compare farm-scale production costs, potential ethanol production, and net energy balances[b] for the three systems were then conducted. Erosion and N leaching to groundwater for the three systems were also compared.

The analysis shows a series of tradeoffs for the three crop systems. Continuous corn may produce the most ethanol and net energy, but is the least efficient at doing so, generating only about 1.9 times the amount of energy that it consumes during crop production, crop and co-product transportation, and ethanol production. It has the greatest risk of soil erosion and N leaching loss. Continuous corn may have the greatest production costs, but it also may return the greatest profit to farmers.

Comparatively, alfalfa-corn will produce less ethanol and net energy, but more efficiently, with less risk of soil erosion, and virtual elimination of N fertilizer use and leaching. Production costs will be less for alfalfa-corn than continuous corn, but profits may also be less.

The analysis shows that rotating alfalfa into a continuous corn system would increase the efficiency of energy production by about

25%, and would decrease on-farm energy requirements by about 38%. However, it would also decrease ethanol yield/ac by about 36% and net energy yield/ac by about 13%. Future alternative management practices for alfalfa, such as a single cut system, in-field separation of stems and leaves, and establishment of alfalfa within the final year of a corn crop to increase first-year alfalfa yields, could all help improve the energy and ethanol yield of an alfalfa-corn rotation.

Switchgrass will produce the least ethanol and net energy, but will do so most efficiently, generating 6.3-7.8 times the amount of energy consumed; and it does so with little soil erosion. Nitrogen fertilizer use and N leaching will be less for switchgrass than corn, but much greater than for alfalfa-corn. Switchgrass may be the least expensive crop system to produce, but may return a profit only if selling prices or yields are high.

The analysis shows that switchgrass may not return the potential income to farmers that alfalfa and corn could unless both switchgrass prices to farmers were at least $60/ton and yields were at least 5 tons/ac. Both of these conditions may not be readily achieved given present economic forecasts for cellulosic ethanol production and yields in commercial production environments. Switchgrass may also require significant annual N fertilizer to produce high yields.

Given that it is a perennial crop that will likely be grown for at least ten years, switchgrass also offers limited potential on agricultural lands that producers may need for shorter crop rotations. Instead, switchgrass may be better suited to marginal or erosion-prone agricultural lands already set aside from traditional crop rotations, such as in the Conservation Reserve Program or in riparian buffer strips. Farmers may also benefit financially from Conservation Reserve Program payments or buffer programs when using switchgrass in such scenarios, although the Conservation Reserve Program regulations would have to change to allow harvest.

Clearly, the analysis of production costs and energy balances for potential biofuel crop systems demonstrates that different crop systems will have both advantages and disadvantages. Production of one system over another will likely depend on a variety of factors, including the ability and need to produce a given volume of ethanol, the desire to protect environmental quality and natural resources, the promotion of rural economic growth and stability, and current and future farm production strategies and goals.

It is thus likely, and perhaps most desirable, that cellulosic ethanol feedstock production will consist of a variety of crops that meet the needs and abilities of different regions and individual producers within those regions.

[a] *While alfalfa-corn rotations may typically have three or more years of alfalfa, only two years were chosen to take advantage of greater ethanol yield from corn than alfalfa, while still gaining two years of N credits from the alfalfa crop for the corn production.*

[b] *For each crop system, energy inputs included energy required to grow and harvest crops; energy required to transport all harvested crops, alfalfa leaf meal and stems, and distillers grains; and energy required to produce ethanol at a conversion facility. Energy outputs included energy contained in the potential ethanol produced, alfalfa leaf meal, and distillers grains. The net energy generated was thus total energy generated in outputs minus the total energy in inputs.*