Fact sheet

U.S. Dairy Forage Research Center
USDA-Agricultural Research Service
Madison, Wisconsin

Adding an alfalfa rotation with corn grown for ethanol improves energy efficiency, reduces environmental impact

Which crop is the best choice for ethanol production? It depends on the ultimate goal and a series of trade-offs (see Figure 1). While corn is the "king" of ethanol production now, 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. Furthermore, corn production requires fairly heavy nitrogen (N) fertilizer applications that can lead to N leaching and degradation of water resources. And 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.

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

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.

Figure 1.

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	medium	least desirable	medium	least desirable	least desirable
alfalfa/corn rotation	medium	medium	medium	medium	medium	least desirable	medium	most desirable	medium	most desirable
switch grass	most desirable	least desirable	most desirable	most desirable	least desirable	most desirable	most desirable	least desirable	most desirable	medium

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 can be grown in almost every part of the country and averages 3.5 tons/acre of dry matter each year. The technology and machinery for cultivating, harvesting, and storing alfalfa is widely available, and farmers are familiar with alfalfa production. 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.

Economic and environmental analysis of the three systems . . .

To compare the advantages and disadvantages of different cropping systems for ethanol production, we looked at three possible crop rotations:

- 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, we assessed both "normal" and "high" crop yield scenarios (Table 1). We 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, we considered low, medium, and high commodity price scenarios (Table 2). And then we conducted an analysis to compare farm-scale production costs, potential ethanol production, and net energy balances for the three systems (Figure 1). Energy inputs and outputs are shown in Figure 2. We also compared erosion and N leaching to groundwater for the three systems (Table 3).

[a] While alfalfa-corn rotations typically have three or more years of alfalfa, we chose only two years to provide two years of greater ethanol yield from corn while still gaining two years of N credits from alfalfa (for subsequent corn production).

Our analysis shows a series of trade-offs for the three crop systems (Figure 1). Continuous corn may produce the most ethanol (Figure 3) and net energy (Figure 4), but it is the least efficient at doing so (Figure 5), generating only about 2 times the amount of energy that it consumes during crop production, crop and co-product transportation, and ethanol production; and it has the greatest risk of soil erosion and N leaching loss (Table 3). Continuous corn may have the greatest production costs, but it also may return the greatest profit to farmers (Figure 6).

Comparatively, alfalfa-corn will produce less ethanol

Table 1.	Crop Yield[a] (tons/acre)	
Crop System	Normal	High
Alfalfa-corn rotation		
alfalfa establish	2.0	3.0
alfalfa production	4.0	6.0
corn grain yr. 1	4.3 (155 bu)	5.6 (200 bu)
corn grain yr. 2	3.8 (135 bu)	4.9 (175 bu)
corn stover yr. 1	2.7	3.4
corn stover yr. 2	2.3	3.0
Continuous corn		
grain	3.8	4.9
stover	2.3	3.0
Switchgrass		
	4.0	6.0

[a] Yields are on a dry weight basis, except corn grain which is 15.5% moisture.

Table 2.	Prices used in analysis		
Crop	Low	Med.	High
corn grain	$2/bu	$3/bu	$4/bu
corn stover	$20/ton	$30/ton	$40/ton
alfalfa	$60/ton	$80/ton	$110/ton
switchgrass	$30/ton	$60/ton	$90/ton

Table 3.	Nitrogen loss (lb. N/acre)	
Crop Yield	Normal	High
Alfalfa-corn rotation		
leaching	2.8	3.0
denitrification	6.2	7.4
Switchgrass		
leaching	5.6	7.2
denitrification	8.1	12.3
Continuous corn		
leaching	14.4	7.6
denitrification	34.9	21.7

Energy Comparison Figures

Figure 2.

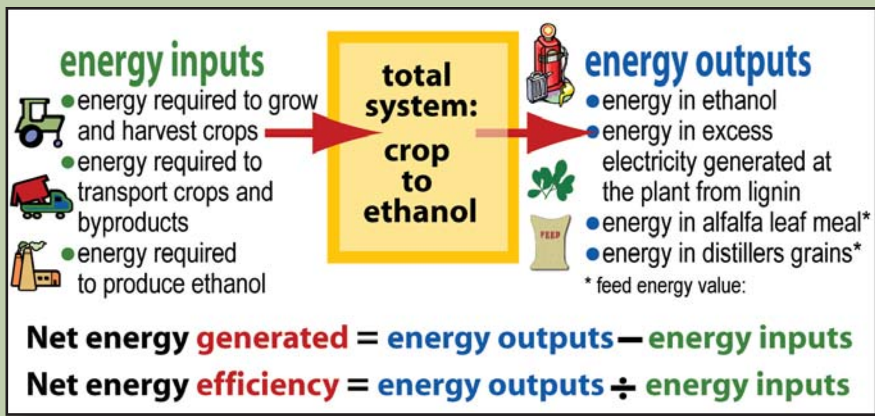


Figure 3.

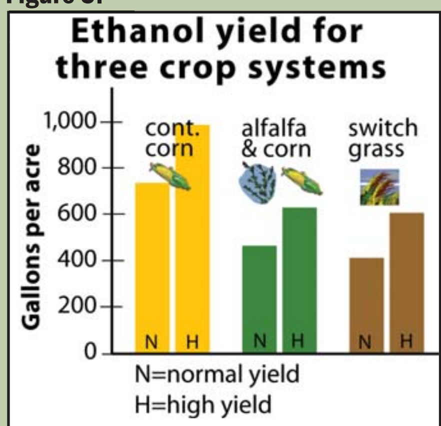


Figure 4.

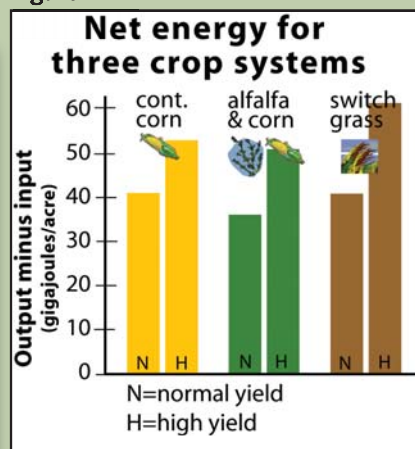
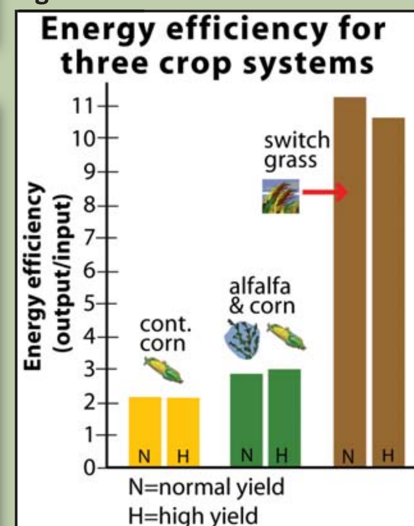


Figure 5.



and net energy (Figures 3 and 4), but more efficiently (Figure 5) and with a lesser risk of soil erosion and virtual elimination of N fertilizer use and leaching loss (Table 3). Production costs will be less for alfalfa-corn than continuous corn, but profits may also be less (Figure 6). Our analysis shows that rotating alfalfa into a continuous corn system would increase the efficiency of energy production by about 33%, and would decrease on-farm energy requirements by about 38%. However, it would also decrease ethanol yield per acre by about 35% and net energy yield per acre by about 6%. 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 (Figures 3 and 4), but will do so most efficiently (Figure 5), generating about 11 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 greater than for alfalfa-corn (Table 3). Switchgrass may be the least expensive crop system to produce, but may return a profit only if selling prices or yields are high (Figure 6). Our 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 $75 per ton and yields were at least 5 tons/acre. 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 10 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, our 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.

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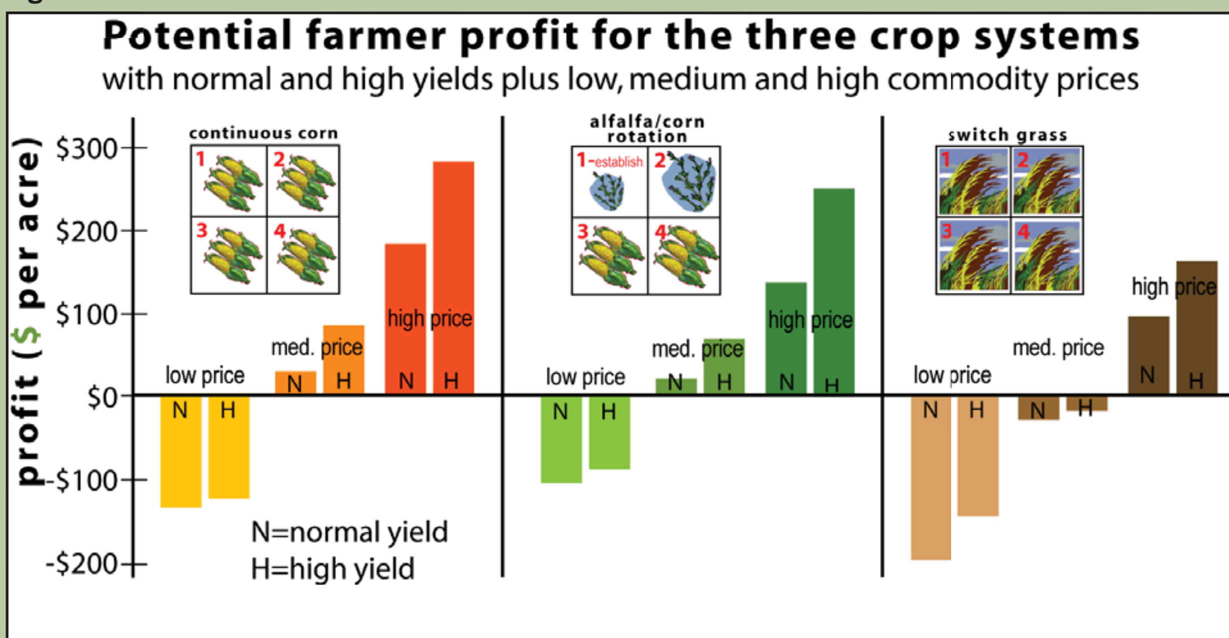
It is thus likely, and perhaps most desirable, that cellulosic ethanol feedstock production will consist of a variety of crop systems that meet the needs and abilities of different regions and individual producers within those regions.

Figure 6.



This FactSheet is based on a study by Peter Vadas, U.S. Dairy Forage Research Center, USDA-Agricultural Research Service; Dan Undersander, University of Wisconsin-Madison; and Ken Barnett, University of Wisconsin Extension, Wausau.

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