

ALFALFA: POTENTIAL FOR NEW FEED AND BIOFUEL – USDFRC RESEARCH UPDATE

Neal P. Martin and Hans-Joachim G. Jung¹

ABSTRACT

Alfalfa hay is a major crop supporting U.S ruminant livestock industry, particularly dairy. Several cellulosic feedstocks will be needed to meet current ethanol production goals. Alfalfa has considerable potential as a feedstock for production of ethanol and other industrial materials because of its high biomass production, perennial nature, ability to provide its own nitrogen fertilizer, and valuable co-products. Alfalfa stems are an excellent feedstock for cellulosic ethanol via fermentation or gasification. Fractionation processes can produce alfalfa leaf meal (ALM) with protein content comparable to protein in dried distiller's grains. Adding high value products from either fraction of alfalfa from non livestock uses will add value to alfalfa biomass use for biofuel. When a biomass-type alfalfa is grown under a biomass management system with less dense seeding and only two harvests per year, compared with standard hay-type alfalfa production practices, total yield of alfalfa increases 42%, leaf protein yield is equal, and potential ethanol yield from stems doubles. Alfalfa grown in rotation with corn to produce biomass for ethanol production reduces nitrogen loss from leaching and denitrification of corn with minimal reduction in profitability of corn.

Keywords: Alfalfa hay, biomass, ethanol, leaf meal, crude protein

Acreage and Production



In 2008, U.S. farmers harvested alfalfa as hay and haylage from 23 million acres. Alfalfa forages partially supply nutrient needs in diets of dairy, beef, sheep, and horse livestock. Alfalfa remains the main perennial forage fed to dairy cattle in the West.

The United States is experiencing an economic shock due to recent hikes in the price of oil and natural gas. For farmers, the prices of nitrogen fertilizer and fuel have risen to unprecedented levels, putting profits at risk. The President, Congress, industry, and the public are all calling for

¹ Neal Martin, U. S. Dairy Forage Research Center, USDA-ARS, 1925 Linden Drive West, Madison, WI 53706; Hans-Joachim G. Jung, USDA-ARS, St. Paul, MN. Proc for the 2010 Winter Seed School Conference, Golden Nugget, Las Vegas, NV, January 17-19, 2010. Pp 105-111.

independence from imported oil. Ethanol produced from cellulosic biomass may be a sustainable and achievable alternative to help fuel America's transportation system. At the same time, biomass crops must help support profitable agricultural systems, vital rural towns, and public demand for environmental protection.

Alfalfa has considerable potential as a feedstock for production of ethanol and other industrial materials because of its high biomass production, perennial nature, ability to provide its own nitrogen fertilizer, and valuable co-products. Unlike other major field crops

like corn and soybeans, which are commonly refined for production of fuel and industrial materials, refining of alfalfa remains under developed. Instead, alfalfa is primarily processed and used on-farm as livestock feed. Although alfalfa follows wheat as the fourth most important field crop after corn and soybeans, declining dairy cow numbers and shifts in feeding practices have caused a reduction in alfalfa acreage over the last 25 years. The end result has been an increase in continuous row cropping of corn and soybeans with little rotation to perennial forages. As a result, the risks of soil erosion, contamination of surface and ground water by nitrate and pesticides, and loss of valuable soil organic matter have increased. Growing more alfalfa for biofuel production would contribute to making the United States energy independent, improving our natural soil resource, reducing greenhouse gas emissions, and protecting water quality.

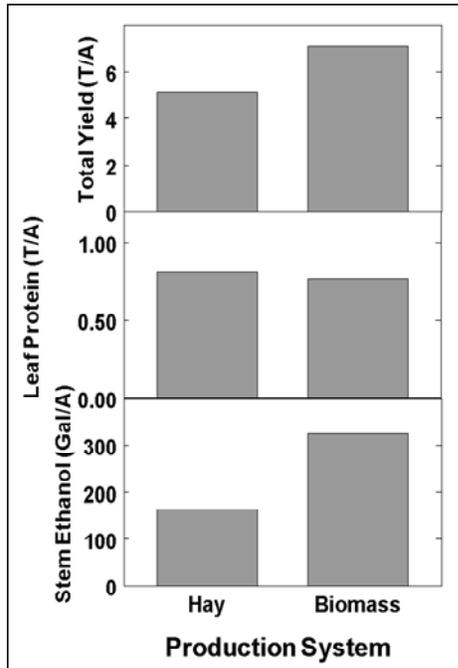


Figure 1: Dry matter, leaf protein, and theoretical ethanol yield from stems of hay-type alfalfa grown under conventional hay management compared to biomass-type alfalfa grown under a biomass management system.

SOURCE: Lamb et al., 2007.

The USDA-Agricultural Research Service is actively researching many potential biomass crops. The Plant Science Research Unit (PSRU) in St. Paul, MN has been involved in alfalfa biomass energy research since 1993 in collaboration with the University of Minnesota.

The PSRU has developed a biomass-type alfalfa that is taller and does not lodge at later maturity stages. These traits allow less frequent harvesting than conventional forage-type alfalfa which reduces harvest costs and protects nesting birds in early summer. When biomass-type alfalfa is grown under a biomass management system with less dense seeding and only two harvests per year, compared with standard hay-type alfalfa production practices, total yield of alfalfa increases 42%, leaf protein yield is equal, and potential ethanol yield from stems doubles (Figure 1).

Alfalfa produces high net energy yield – that is, the energy required for production is far lower than the total energy contained in the crop. This is due, in part, to biological nitrogen fixation. Unlike corn and other grass crops, alfalfa can obtain nitrogen from the air. This saves the farmer money, but also represents a tremendous energy savings. Furthermore,

alfalfa residues leave enough plant-available nitrogen in the soil to meet the needs of the next crop of corn. In many cases, there is even enough nitrogen to satisfy one-half the need of the second crop of corn. Clearly, inclusion of alfalfa in rotation with corn increases the efficiency of energy production from corn, see figure on right.

To maximize energy yield, cellulosic biomass production and processing likely will need to be locally based. Recently, PSRU scientists analyzed the spatial distribution of net energy yield for soybeans, corn, and alfalfa in a prospective fuel shed, and the results demonstrate how net energy yield varies with soil type and decreases with distance from processing facilities. This approach has shown how biofuel facility planners can minimize costs and maximize energy production by contracting with nearby, high-producing farms. In addition to the many environmental benefits of growing a perennial legume, the efficiency of energy production from alfalfa is 2 to 3 times better than corn grain or soybeans. Below (Table 1) are examples for specified biomass yields in fields located 15 miles from a processing facility.

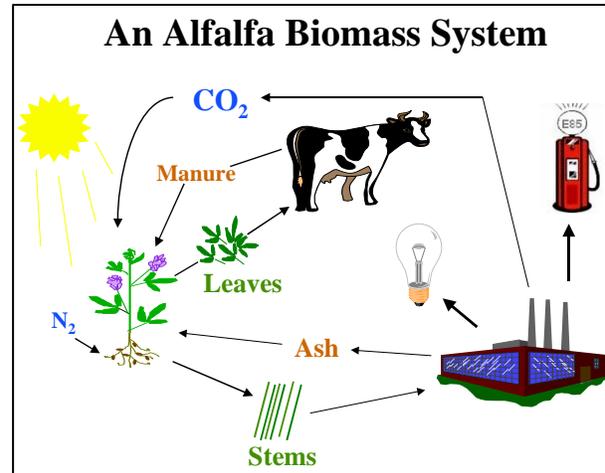


Table 1: Biomass yields in fields located 15 miles from a processing facility.

Crop (yield)	Energy input	Delivered energy	Ratio of output:input
	Million BTU/acre		
Soybean (40 bu/a)	2.3	18.3	7.1
Corn grain (180 bu/a)	6.0	59.0	8.8
Corn stover (3.6 tons/a)	2.6	51.1	19.7
Alfalfa (6 tons/a)	3.0	78.2	25.0

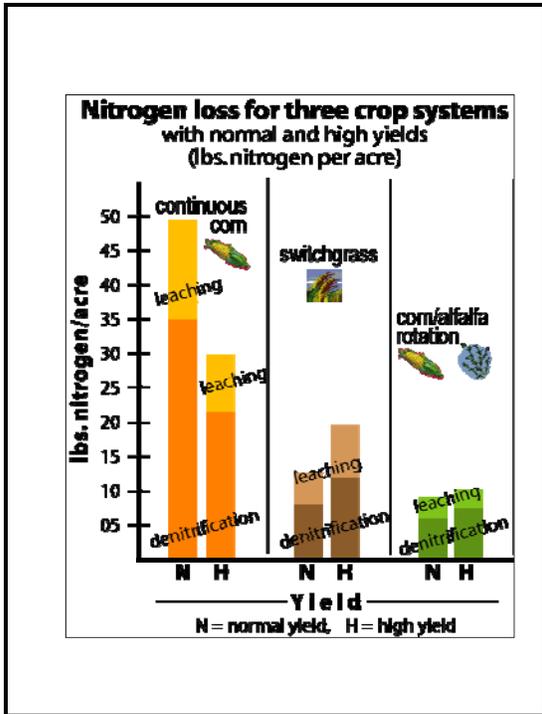
Source: Michael Russelle, unpublished.

In contrast to new crops and native perennials, production practices and machinery are well developed for alfalfa. There is agronomic expertise available in most states through the Extension service and private consultants. Additionally, several

value-added products can be produced from alfalfa leaves before conversion of the rest of the crop to fuel or energy. Examples are feed and food grade proteins, and nutraceuticals such as lutein. Scientists in the PSRU have produced bio-degradable plastic in alfalfa leaves.

While corn is “king” of ethanol production now, alfalfa could be a good “queen” to corn for a variety of reasons. While switchgrass is widely considered feedstock option for future cellulosic ethanol production, alfalfa has a number of characteristics already mentioned that make it a stronger candidate.

Dairy forage research Center, Vadas et al. 2008, compared advantages and disadvantages of growing continuous corn for 4 years, an alfalfa-corn rotation (two years alfalfa, two years corn), and continuous switchgrass for four years. Each crop system was assessed at a normal



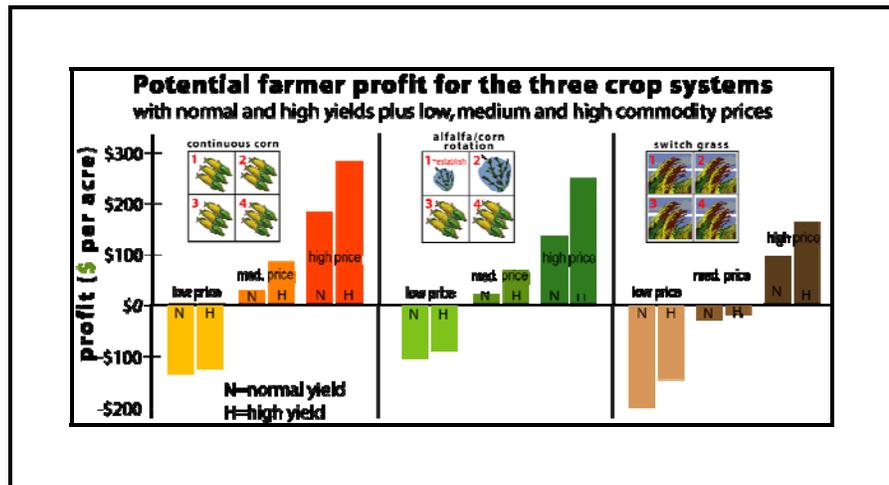
and high yield level. Alfalfa hay was harvested from a farm and sold to a separation facility that would in turn sell alfalfa leaf meal to farms and stems to ethanol facility. To gain an estimate of potential profits to farmers across entire crop systems low, medium and high price scenarios were analyzed across all systems. The analysis conducted to compare farm-scale production costs, potential ethanol production and net energy balances for the three systems. In addition, a comparison of soil erosion and N leaching to ground water for each system was developed.

Continuous corn may produce the most ethanol and net energy, but it is the least efficient at doing so, 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.

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 and with a lesser risk of soil erosion and virtual elimination of N fertilizer use and leaching loss. Production costs will be less for alfalfa-corn than continuous corn, but profits may also be less. 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 6 %.

Future alternative management practices for alfalfa, such as a single cut system, in-field separation of stems and leaves, and establishment of alfalfa first-year yields, could all help improve the energy and ethanol yield of an alfalfa-corn rotation.



The technologies currently in place to convert lignocellulosic biomass to energy are either biochemical or thermochemical, the efficiencies of which may vary depending on the composition of the feedstock. One variable that conversion technologies have wrestled with, particularly in simultaneous sacchification and fermentation process, is lignin content. Dien et al., 2006 found that lignin content negatively influenced total glucose yield from dilute-acid pretreatment and enzymatic saccharification for several herbaceous species including alfalfa, reed canarygrass and switchgrass. While lignin is considered a recalcitrant to biochemical conversion, it can be a good source of combustion fuel, but the true effect of combustion on thermochemical conversion has not been well quantified. Lignin concentration was negatively related to in-vitro gas production at both incubation times examined by Dien et al., 2006., and it accounted for approximately 80 % of the variation in in-vitro gas production. In contrast, yields of only three noncondensable gases (CH₄, C₃H₄ and H₂) were related to lignin concentration and these relationships were only observed for a limited set of pyrolysis temperatures. This research showed lignin had a much larger effect on biochemical conversion potential than it did on thermochemical conversion potential.

Fluidized-bed fast pyrolysis of alfalfa stems harvested at full flower and early bud stage was performed, Boateng et al., 2008. Bio-oil yields were lower (45%-53%) than that typically observed for the fluidized-bed fast pyrolysis of biomass. However, the bio-oils produced from alfalfa stems had higher caloric value than most bio-oils, with high heating values (HHV) that were approximately two-thirds of that of crude oil, whereas bio-oil usually has HHV that is approximately half that of crude oil. The more mature full-flower stem feedstock contained more cellulose and lignin and less ash than the less mature feedstock. Overall energy recovery from alfalfa stems was higher for more mature because the energy content of bio-oils, charcoal and noncondensable gas co-products.

Alfalfa Leaf Meal (ALM)

The Minnesota Valley Alfalfa Processors (MNVAP), Priam, MN have separated alfalfa leaves from stems by grinding alfalfa hay and passing it through screens. The proportion of leaves and stems in alfalfa hay ranges from 40 to 60 %, based on maturity of alfalfa (40 % at full bloom to 60 % at early bloom). Protein content of alfalfa leaves does not change with maturity. The stems are high in fiber, less digestible, and loose quality rapidly with advancing maturity, primarily due to the lignification of cell walls. Researchers at the University of Wisconsin and the U. S. Dairy Forage Research Center, have developed a prototype one pass forage harvester that separates leaves from stems (Shinners et al., 2007).

The protein content of alfalfa leaves separated by MNVAP averaged 28 % CP (Table 2). Dried

Table 2. Nutrient composition of alfalfa leaf meal and other major ingredients.

Feed	Protein	Fiber	Fat	Calcium	Phosphorus
ALM ¹	28	34	2.8	2.47	0.34
DDGS ²	30	39	10.0	0.22	0.83
SBM ²	50	15	1.6	0.40	0.71
Corn ²	9	10	4.2	0.04	0.30

¹ Dicostanzo et al., 1999. Proc Minnesota Nutrition Conference

² Dairy NRC 2001

distillers grain soluble (DDGS) is listed in the Dairy NRC (2001) as containing 30 % CP, slightly higher than ALM. Fiber contents of DDGS and ALM are similar, but the phosphorus level on ALM is lower than DDGS. Phosphorus soil test levels in dairy regions of U. S. often is excessive; addition of DDGS into dairy diets could lead to higher soil phosphorus tests.

Fuel or Adhesives in Wood Products

U.S. Dairy Forage Research Center scientists have identified a potential high value by-product from bacteria fermenting alfalfa fiber for ethanol. This material is the glycocalyx, a sticky resin formed by the bacteria that adhere to the fiber. Fermentation residues (consisting of incompletely fermented fiber and adherent bacterial cells with their glycocalyx material) were obtained by growing the anaerobic cellulolytic bacteria *Ruminococcus albus* 7 or *Clostridium thermocellum* ATCC 27405 on a fibrous fraction derived from alfalfa. Dried residue served as an effective co-adhesive for phenol-formaldehyde (PF) bonding of aspen veneer sheets to one another. Testing of resulting plywood panels revealed that the adhesive, formulated to contain 30% of its total dry weight as fermentation residue, displayed shear strength and wood failure comparable with industry standards (plywood normally contains 55 % by weight of PF). Alfalfa fiber plus microbial glycocalyx has potential to replace phenol-formaldehyde resin currently used in forming plywood panels.

Further research on alfalfa germplasm improvement, development of valuable co-products, and providing guidelines for the most environmentally beneficial deployment of alfalfa in cropping systems will strengthen the economic and environmental benefits to be gained from using alfalfa to provide the future energy needs of the United States.

Summary

Cellulosic feedstock from a variety of crops and waste products is needed to produce ethanol. Cellulosic ethanol has not yet been produced on a commercial scale. Alfalfa has potential as a feedstock for ethanol and as a new leaf meal supporting livestock. Research continues to evaluate the influence of alfalfa stem composition on biochemical and thermochemical conversion. Research into improving biomass yield and conversion of biomass to liquid fuel via fermentation or gasification can generate new products and expanded acreage.

Literature Cited

Boateng, A.A., Mullen, C.A., Goldberg, N.M., Hicks, K.B., Jung, H.G., Lamb, J.F. 2008. Production of bio-oil from alfalfa stems by fluidized-bed fast pyrolysis. *Industrial and Engineering Chemistry Research*. 47:4115-4122.

Boateng, A.A., Weimer, P.J., Jung, H.G., Lamb, J.F. 2008. Response of thermochemical and biochemical conversion processes to lignin concentration in alfalfa stems. *Energy and Fuels*. 22:2810-2815.

DiCostanzo, A., C. M. Zehnder, J. M. Akayezu, M. A. Jorgensen, J. M. Cassidy, D. M. Allen, D. G. Standorf, J. G. Linn, H. G. Jung, L. J. Smith, G. C. Lamb, D. Johnson, H. Chester-Jones, and G. Robinson. 1999. Use of Alfalfa Leaf Meal in Ruminant Diets. 60th Minnesota Nutrition Conference, Bloomington, MN, Sept 20-22, p. 64-75.

Dien, B.S., Jung, H.G., Vogel, K.P., Casler, M.D., Lamb, J.F., Iten, L.B., Mitchell, R., Sarath, G. 2006. Chemical composition and response to dilute-acid pretreatment and enzymatic saccharification of alfalfa, reed canarygrass, and switchgrass. *Biomass and Bioenergy*. 30:880-891.

Lamb, J.F.S., H.G. Jung, C.C. Sheaffer, and D.A. Samac. 2007. Alfalfa leaf protein and stem cell wall polysaccharide yields under hay and biomass management systems. *Crop Sci*. 47:1407-1415.

National Research Council. 2001. Nutrient requirements of dairy cattle, 7th rev. ed. National Academy Press, Washington, DC.

Shinners, K. J., M. E. Herzmann, B. N. Binversie, and M. F. Digman. 2007. Harvest fractionation of alfalfa. *Trans. ASABE* 50:713-718.

Vadas, P.A., Barnett, K.H., Undersander, D.J. 2008. Economics and energy of ethanol production from alfalfa, corn, and switchgrass in the Upper Midwest, USA. *Bioenergy Research*. 1:44-55.