ABSTRACT

Alfalfa hay utilization by dairy cattle has expanded in western dairy states. Alfalfa silage utilization has increased in the Midwest. Alfalfa haylage contains high levels of nonprotein nitrogen (NPN) due to protein breakdown during fermentation. Excessive levels of NPN in alfalfa silage diets require supplementation of protected protein sources to meet protein demands of high-producing cattle. Alfalfa hay contains less NPN than alfalfa silage, 10 vs 52% of total nitrogen for hay and silage, respectively. Addition of high-quality alfalfa hay or haylage into dairy cow diets that is low in NDF increases dry matter intake and buffers rumen pH provided fiber length is effective. Alfalfa forage needs to be modified to protect protein in the silo and the rumen and to increase fiber digestion to maintain high levels of alfalfa in dairy cow diets. New uses of alfalfa to remove nitrates from contaminated soils and new processing of valued-added alfalfa products increase the potential of alfalfa being included in crop rotations of cash crops. Processing alfalfa to obtain new value-added products includes three different fractionation methods: 1) wet fractionation (separation into a juice fraction and a fiber fraction); 2) dry fractionation (separation into leaves and stems); and 3) fractionation by passage of the whole herbage through the digestive systems of ruminant animals, leaving a high fiber residue. Phytase from transgenic alfalfa has been tested in poultry and swine rations. Chicks supplemented with phytase from transgenic alfalfa juice or leaf meal had growth equal to chicks fed phosphorus-supplemented rations; manure from the chicks supplemented with alfalfa phytase contained less than half the phosphorus levels of manure from chicks fed inorganic phosphorus supplements. Alfalfa hay can be fractionated to yield stems and leaf meal. Alfalfa leaf meal has been shown to be an acceptable supplement to replace a portion of alfalfa hay and soybean meal in diets of lactating dairy cattle; it can also replace protein supplements in beef cow diets, finishing steer diets and diets of growing turkeys. The fiber portion of alfalfa can produce lactic acid and ethanol. The fiber from alfalfa manure has yielded pressboard and water filters capable of removing heavy metals from contaminated water.

Key Words: alfalfa, corn, hay, silage, fractionation, transgenic, phytase, and enzymes

INTRODUCTION

Approximately 85 million tons of alfalfa were harvested from U.S. farms in 2003. The alfalfa hay harvest was valued at $6.9 billion, ranking behind only corn, soybeans and wheat. Alfalfa hay supports dairy, beef and sheep production in the U.S. Alfalfa hay acreage and production has remained constant in recent years. Alfalfa hay production is moving west with the rapid growth of the dairy industry. Dairy farm numbers are decreasing in the East and increasing in the West.

N. P. Martin (npmartin@wisc.edu), D. R. Mertens, and P. J. Weimer, Center Director, Dairy Scientist, and Microbiologist, respectively, U. S. Dairy Forage Research Center, USDA-ARS, 1925 Linden Drive West, Madison, WI, 53706.

declining most rapidly in dairy regions of the Midwest. Beef cow-calf production remains relatively constant on U.S. farms.

Lactating dairy cattle and highly performing horses require high-quality hay that demands premium prices. Dairy operators primarily use alfalfa haylage or hay and corn silage. Corn silage production has been increasing on many dairy farms. In addition, dairy farm size is expanding which increases animal density and the concentration of manure nutrients. Expansion of alfalfa production and use will depend on the demand from dairy, beef, and horse managers. As new government regulations require nutrient management plans for soils high in nitrate nitrogen and or phosphorus, the need for crops that remove excessive nitrate or phosphorus become more important. Alfalfa can remove excessive nitrate levels reported under corn and soybean crop rotations.

Alfalfa in comprehensive nutrient plans holds potential for increasing alfalfa hay acreage. However, cash crop farmers do not have equipment to harvest alfalfa nor are the profit potentials attractive unless new value-added products from alfalfa can be developed.

Research efforts are underway to develop alfalfa with value-added traits and to develop new processing technologies for new products.

Alfalfa production must remain profitable for growers. The keys to profit are production, price, cost control, and volume of production. Major factors to increase utilization are yield enhancement, forage quality enhancement, and new products.

**ALFALFA UTILIZATION BY DAIRY CATTLE**

We believe the value of high-quality alfalfa for dairy cows is that it reduces grain and protein needs by providing variable protein content and solubility, as well as relatively high energy. But the unique value is that it promotes greater intake and milk production by containing low NDF, faster rates of digestion, particle size reduction (its coarse structural fiber that stimulates ruminative chewing and salivation which results in rumen buffering), and rate of passage. California dairy nutritionists and ranchers value alfalfa for its slowly rumen-degraded protein, rapidly rumen-fermented non-structural carbohydrates, as well as its high energy value for high-lactating dairy cattle (Robinson, 2003).

Alfalfa harvesting in the Midwest has shifted from hay to haylage because of reduced risk of weather-damaged alfalfa and the greater mechanization of alfalfa harvesting.

**Proportion of Alfalfa Silage and Corn Silage in diet.** An experiment was conducted to determine if there is an optimum mix of alfalfa and corn silage in a dairy ration in terms of animal performance (Dhiman and Satter, 1997). The experiment started at calving and lasted until cows completed 44 weeks of lactation. Forty-five mature cows and 29 first lactation cows were randomly assigned before calving to one of three treatments according to calving date. Cows were fed diets containing 50% forage and 50% concentrate. The forage portion of the diet was either all alfalfa silage (AS), 2/3 alfalfa silage and 1/3 corn silage (2/3 AS), or 1/3 alfalfa silage and 2/3 corn silage (1/3 AS).

Milk production totals, unadjusted for milk fat content for mature cows for the 305-day lactation for the AS, 2/3 AS, and 1/3 AS treatments were 21, 148, 22, 422 and 22, 100 lb; and for first lactation cows were 17, 911, 18, 546, and 18, 008 lb. From the point of view of animal performance only, the 2/3 alfalfa silage-1/3 corn silage diet was optimal, but not much better than the 1/3 alfalfa silage-2/3 corn silage treatment. The important point is that while there appears to be an optimum blend of the two forages, the difference in milk production is modest when comparing different proportions of the two forages.

Less total protein was fed when the diets contained corn silage, but more supplemental protein was required. Feeding a blend of low-protein corn silage with the high but easily degraded alfalfa protein enabled more efficient utilization of protein in the rumen. This resulted in less nitrogen excretion per unit of milk produced when the forage mixture was used. It is suggested that dairy producers feed a minimum of 1/3 alfalfa (hay or silage) and 1/3 corn silage, and let the remaining third be distributed between the two forage sources according to what works best for the dairy producer’s particular situation.
Protein Utilization of Alfalfa. Broderick and Satter (1998) reported that alfalfa haylage harvested in Wisconsin and Minnesota averaged 55% non-protein nitrogen (NPN). Over half of the crude protein (CP) coming from alfalfa haylage out of the silo was not in the form of true protein. Although rumen microbes can use NPN, too much of this NPN will be converted to ammonia. Most ruminal ammonia will be absorbed from the rumen, carried by the blood to the liver, and converted to urea and excreted in the urine. However, unlike silage, alfalfa hay has little non-protein nitrogen (NPN) – about 10% of total nitrogen.

Center scientists compared the performance of lactating cows fed all their forage as either alfalfa silage or alfalfa hay in two trials (Broderick, 1995). Magnitude of the production response to high by-pass protein (fish meal) was used to determine which diet was most adequate in protein before supplementation. Alfalfa was harvested from alternate windrows as either 60% moisture silage or dry hay in small bales. Diets averaged (dry matter basis) 67% alfalfa and 30% high-moisture corn. Although the silage and hay had similar levels of NDF, (average of 38%), the hay averaged 2.5 percentage units less protein than silage (18.1 versus 20.6% protein). Lower crude protein in hay was due to the greater leaf loss that typically occurs during hay harvesting (Nelson and Satter, 1992). Average NPN (% of total nitrogen) content was 52% in alfalfa silage and 8% in hay. Production data are shown in Table 1. Cows had lower dry matter intake, lost weight, and produced less milk, protein, and solids (not fat) on alfalfa silage without fish meal than on the other three diets.

Addition of fish meal increased protein yield 0.22 lb/day on alfalfa silage, but only 0.07 lb/day on alfalfa hay. This means that the hay diet yielded a greater protein supply before supplementation than did the silage diet. Ruminal ammonia was higher at all times after feeding silage than hay; ammonia averaged 21.6 and 11.3 mg N/100 ml on the alfalfa silage and alfalfa hay diets, respectively. When samples of these same forages were incubated in artificial rumens, microbial protein breakdown formation was 29% greater on hay than on silage (Peltekova and Broderick, 1996). Lower concentration of protein breakdown products in the artificial rumens indicated that hay protein was degraded more slowly and at a rate that was more in synchrony with energy digestion. This may explain the greater formation of microbial protein on hay than on silage.

New machinery developments may help mechanize field harvesting of hay, and compensate for the lack of farm labor. Koegel et al. (1988) developed an alternative hay-making process that extensively shreds...
herbage prior to forming it into thin forage mats for field-drying. Drying rates of the shredded alfalfa mats were three times faster than those for conventionally conditioned alfalfa. The shredded alfalfa had 15% more digestible energy than conventional alfalfa (Hong et al., 1988) and slightly greater bypass protein (Yang et al., 1993).

Broderick and Satter (1998) summarized data from a lactation study with dairy cows fed a high haylage diet. The study used two products, formic acid and Grainmax (a product containing mineral acids and formaldehyde), to reduce the level of proteolysis of silage during fermentation. The formic acid treatment not only reduced NPN in haylage (43 vs 29% NPN of total protein for control and formic acid-treated silage, respectively), but also increased protein yield of the milk by 14% (Table 2). This action not only improved milk protein, but also reduced the need for expensive undegradable protein supplements, and more important to dairy farming in the 21st century, it reduced the N content in urine and manure.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control (C)</th>
<th>Formic acid (F)</th>
<th>Grainmax (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>61.7</td>
<td>64.8</td>
<td>64.1</td>
</tr>
<tr>
<td>CP of DM</td>
<td>21.4</td>
<td>20.8</td>
<td>21.1</td>
</tr>
<tr>
<td>NPN, of total N</td>
<td>43.1</td>
<td>29.1</td>
<td>35.5</td>
</tr>
<tr>
<td>NDF, of DM</td>
<td>38.9</td>
<td>41.2</td>
<td>41.3</td>
</tr>
<tr>
<td>Intake &amp; product</td>
<td></td>
<td>Lb/day/hd</td>
<td></td>
</tr>
<tr>
<td>DM intake</td>
<td>40.3</td>
<td>40.1</td>
<td>43.4</td>
</tr>
<tr>
<td>Milk</td>
<td>64.4</td>
<td>71.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>71.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat</td>
<td>2.43&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.87&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Protein</td>
<td>1.79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.92&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Average with different superscripts are significantly different (P< 0.05).
<sup>1</sup>DM = Dry matter.
<sup>2</sup>Diets contained 98% of total DM from the experimental alfalfa silage.
<sup>3</sup>Control silage untreated.
<sup>4</sup>Silage ensiled after add 2.0 gal/ton of 90% formic acid.
<sup>5</sup>Silage ensiled after add 1.5 gal/ton of Grainmax and 16% formaldehyde.

University of Wisconsin and USDA-ARS research, summarized by Broderick and Satter (1998) reported that red clover silage contains as much as 30 to 40% less NPN than alfalfa silage of comparable forage quality. The protein in red clover is degraded less during fermentation due to an enzyme called polyphenol oxidase (PPO), which inhibits action of plant proteases during ensiling. If the gene, which makes PPO in red clover, can be identified, it would be a trait, which if inserted into alfalfa, would improve alfalfa haylage utilization. Protein utilization of alfalfa could also be improved by transgenic lines containing storage proteins that are less ruminally degradable as well as lines with lower levels of proteases, but a transgenic line with reduced bloat potential would be tremendous.

**COMPOSITION OF ALFALFA HAY AND CORN SILAGE**

**Alfalfa Hay.** Recently at the California Nutrition Conference, Mertens (2003) compared western alfalfa hay (AH) to corn silage (CS). Although the Dairy NRC (NRC, 2001) does not provide data for exceptional and very high qualities of AH, the crude protein, ash, crude fat, fiber, and lignin values from this study (Table 3) agreed with those of similar quality found in the Dairy NRC. The difference between aNDF and ADF is an estimate of hemicellulose. For AH, this difference is a slight underestimate of hemicellulose because 10 to 20% of the pectin is not extracted by acid detergent. The main NDF in alfalfa is pectin.
Although pectin is rapidly fermented and is included in the NDS fraction, it ferments in the rumen like other fibrous constituents, its fermentation is sensitive to low ruminal pH, and it results in the production of acetic acid. Starch fermentation, on the other hand, is less sensitive to ruminal pH and results in the production of propionic and lactic acids in the rumen.

Table 3. Typical composition of alfalfa hays and corn silages varying in fiber content.

<table>
<thead>
<tr>
<th>Forage/Description</th>
<th>CP a</th>
<th>EE b</th>
<th>Ash</th>
<th>NFC c</th>
<th>Star d</th>
<th>Pec e</th>
<th>aNDF f</th>
<th>ADF g</th>
<th>ADL h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exceptional quality</td>
<td>25.4</td>
<td>2.7</td>
<td>10.4</td>
<td>31.5</td>
<td>3.1</td>
<td>14.2</td>
<td>30.0</td>
<td>24.0</td>
<td>4.53</td>
</tr>
<tr>
<td>Very high quality</td>
<td>24.0</td>
<td>2.6</td>
<td>9.9</td>
<td>29.4</td>
<td>2.9</td>
<td>13.2</td>
<td>34.1</td>
<td>27.0</td>
<td>5.38</td>
</tr>
<tr>
<td>High quality</td>
<td>22.5</td>
<td>2.5</td>
<td>9.5</td>
<td>27.4</td>
<td>2.7</td>
<td>12.3</td>
<td>38.2</td>
<td>30.0</td>
<td>6.23</td>
</tr>
<tr>
<td>Good quality</td>
<td>21.0</td>
<td>2.4</td>
<td>9.1</td>
<td>25.3</td>
<td>2.5</td>
<td>11.4</td>
<td>42.2</td>
<td>33.0</td>
<td>7.08</td>
</tr>
<tr>
<td>Fair quality</td>
<td>19.5</td>
<td>2.2</td>
<td>8.7</td>
<td>23.2</td>
<td>2.3</td>
<td>10.5</td>
<td>46.3</td>
<td>36.0</td>
<td>7.93</td>
</tr>
<tr>
<td>Very high grain</td>
<td>8.3</td>
<td>3.2</td>
<td>4.1</td>
<td>48.4</td>
<td>31.1</td>
<td>1.9</td>
<td>36.0</td>
<td>21.0</td>
<td>1.57</td>
</tr>
<tr>
<td>High grain</td>
<td>8.6</td>
<td>3.1</td>
<td>4.6</td>
<td>43.2</td>
<td>27.2</td>
<td>1.7</td>
<td>40.5</td>
<td>24.0</td>
<td>1.91</td>
</tr>
<tr>
<td>Normal</td>
<td>8.8</td>
<td>3.0</td>
<td>5.1</td>
<td>38.1</td>
<td>23.2</td>
<td>1.5</td>
<td>45.0</td>
<td>27.0</td>
<td>2.25</td>
</tr>
<tr>
<td>Low grain</td>
<td>9.0</td>
<td>2.8</td>
<td>5.7</td>
<td>33.0</td>
<td>19.2</td>
<td>1.3</td>
<td>49.5</td>
<td>30.0</td>
<td>2.59</td>
</tr>
<tr>
<td>Very low grain</td>
<td>9.3</td>
<td>2.7</td>
<td>6.2</td>
<td>27.8</td>
<td>15.3</td>
<td>1.1</td>
<td>54.0</td>
<td>33.0</td>
<td>2.93</td>
</tr>
</tbody>
</table>

a Crude protein  
b Ether extract or crude fat  
c Nonfiber carbohydrates calculated by difference (NFC = 100 – CP – EE – Ash – aNDF)  
d Starch  
e Pectin, estimated from NFC  
f Amylase-treated neutral detergent fiber determined with sodium sulfite and amylase  
g Acid detergent fiber  
h Acid detergent lignin using 72% sulfuric acid  

In AH, quality is primarily a function of plant maturity. As alfalfa matures, the proportions of fiber and lignin increase and the proportions of crude protein and NFC decrease. The negative relationship between maturity and nutritional value are greatest for early spring plant growth. However, the relationship may not be as strong in regrowth forages, especially those harvested after June 21 when day length and ambient temperature are no longer positively correlated. Plant growing environment can also alter AH composition and digestibility. In general, forages grown in warmer climates have increased fiber and lignification and decreased digestibility. Alfalfa that is stressed by high temperatures or water deprivation is often stunted and may have low fiber concentrations, but it is often higher in lignin, which results in lower digestibility and intake potential.

Corn Silage. Ash values were higher and acid detergent lignin values are lower for corn silage reported in Table 3 than those provided in the Dairy NRC (NRC, 2001), but ADF and aNDF values are similar, which suggests that NRC (2001) results probably were obtained using the aNDF method. The predominant NFC in CS is starch and CS contains very little pectin or neutral detergent soluble fiber (NDSF) as defined by Hall et al. (1997). Corn silage can vary substantially in chemical composition and results in Table 3 were classified by the grain content of the silages because, in general, starch and grain content are related
inversely to fiber concentration. Dry matter (DM) concentration, which is probably the best index of maturity for CS, were not provided in Table 3 because maturity is not as highly related to nutritional quality in CS as it is in other forages. It is often observed that the negative or inverse relationships between fiber or lignin concentration and maturity do not hold for CS. This occurs because CS is a mixture of grain and stover. The lignin concentration of corn stover increases and its digestibility declines with maturity (Daynard and Hunter, 1975; Hunt et al., 1989); however, as the corn plant matures after silking it generates grain that dilutes the concentration and nutritional impact of the maturing stover often resulting in whole plant digestibilities that vary little with maturity.

Weather and environment during corn growth can alter the chemical composition and digestibility of CS. Factors that affect crop height and yield, fiber content and composition, grain content, and translocation of carbohydrates to kernels can affect both composition and availability of nutrients in corn silage. In general, increasing temperature during the growth of plants tends to accelerate maturity, increase lignin and fiber concentration, and decrease digestibility. Moderate water stress may direct photosynthetic material toward seed formation (Van Soest, 1996). Thus, cool and moderately dry growing seasons might result in the highest forage quality for CS (Van Soest and Hall, 1998). However, the timing of temperature and water stress may also be important to the quality of CS.

Van Soest (1996) suggested that accumulated growing degree days (GDD), during the period after silking had a greater impact on composition and quality of CS than accumulated GDD before silking. However, Struik (1983) observed that climatic factors before silking affected fiber digestibility that remain until CS harvest. Andrieu et al. (1993) postulated that the effects of environment before or after flowering on CS may be related to the pattern of corn plant development. Thus, the growing environment before and after flowering may have independent impacts on dry matter digestibility (DMD) of CS. Before silking, temperature and water stress affect plant height and fiber compositions; whereas after silking, water and temperature affect development of grain. If water and temperature are not limiting, the DMD of CS increases with age as more grain is produced and the ratio of NDS to NDF increases. Typically as the corn plant matures we see an increase in grain proportion and changes in CS composition as indicated in Table 3.

Contrasts between alfalfa hay and corn silage. Although the fiber concentrations of AH and CS are very

<table>
<thead>
<tr>
<th>Component</th>
<th>AH 24% ADF</th>
<th>AH 27% ADF</th>
<th>CS proc(^a) 24% ADF</th>
<th>CS proc(^a) 27% ADF</th>
<th>CS unproc(^b) 27% ADF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral detergent fiber (% aNDF)</td>
<td>30.0</td>
<td>34.1</td>
<td>40.5</td>
<td>45.0</td>
<td>45.0</td>
</tr>
<tr>
<td>aNDF digestibility (NDFD, % aNDF)</td>
<td>52.1</td>
<td>46.8</td>
<td>61.4</td>
<td>60.6</td>
<td>60.6</td>
</tr>
<tr>
<td>Digestible aNDF (dNDF = NDFD x aNDF)</td>
<td>15.6</td>
<td>16.0</td>
<td>24.9</td>
<td>27.3</td>
<td>27.3</td>
</tr>
<tr>
<td>Neutral detergent solubles (% NDS)</td>
<td>70.0</td>
<td>65.9</td>
<td>59.5</td>
<td>55.0</td>
<td>55.0</td>
</tr>
<tr>
<td>Digestible NDS (dNDS = .98 x NDS)</td>
<td>68.6</td>
<td>64.6</td>
<td>58.3</td>
<td>53.9</td>
<td>51.3</td>
</tr>
<tr>
<td>True DM digestibility (%)</td>
<td>84.2</td>
<td>80.6</td>
<td>83.2</td>
<td>81.2</td>
<td>78.5</td>
</tr>
<tr>
<td>Endogenous fecal DM excretion</td>
<td>-12.9</td>
<td>-12.9</td>
<td>-12.9</td>
<td>-12.9</td>
<td>-12.9</td>
</tr>
<tr>
<td>Apparent DM digestibility (% DMD(_{10}))</td>
<td>71.3</td>
<td>67.7</td>
<td>70.3</td>
<td>68.3</td>
<td>65.6</td>
</tr>
</tbody>
</table>

\(^a\)Corn silage processed through rollers with a 1-mm clearance.
\(^b\)Unprocessed corn silage assuming that starch is only 90% digestible instead of 98% digestible.
similar at the maturities that we commonly harvest them for dairy rations, the non-fiber components and lignin concentrations differ significantly. Like most legumes, alfalfa has much a higher (2-3X) concentration of lignin than grasses such as corn, which indicates that its fiber digestibility will be lower. Because CS has much less protein and ash content (30-50%) than AH and similar fiber concentration, CS has significantly more NFC, especially when it contains normal or higher proportions of grain. Not only is the concentration of NFC different between AH and CS, but also the composition of the NFC is different. In AH, the major carbohydrates in NFC are pectin and other soluble fibers, but in CS the major NFC is starch. The difference in protein, fiber and NFC between AH and CS suggest that they might complement one another in dairy rations.

The simple summative equation demonstrates that variation in DMD is related primarily to the concentration and digestibility of NDF in feeds (Table 4). Alfalfa hay is similar in digestibility to CS not because its fiber digestibility is superior, but because its aNDF content is lower and NDS content is higher. At similar ADF concentrations, AH has 10 %-units less aNDF, but its aNDF digestibility is only 75-85% of the fiber digestibility of CS. It is reasonable to assume that the starch in CS that has been effectively processed through rollers with a 1-mm clearance and is thoroughly chewed when fed at 1X maintenance will have a digestibility of 98%. However, it is unlikely that the starch in unprocessed CS when fed to lactating cows will attain this efficiency of digestion. The last column in Table 4 provides an estimate of DMD when it is assumed that starch digestion in CS is 90 instead of 98%. Inhibition of starch digestion related to whole kernels has a greater effect than the reduction in ADF concentration by 2 %-units.

Of the true DM digestibility in AH, only 19-20% comes from digestible fiber compared to 30-34% for CS. In both forages, digestible NDS provides the overwhelming majority of DM digestibility. For CS, starch alone provides 28-31% of the true DM digestibility, which is similar to the contribution of digestible fiber in CS. At any level of fiber concentration, it is expected that 95% of the measured NDFD would be within ±10 %-units of the mean values provided in Table 3. Thus the maximum expect change in NDFD from mean would have the same effect on digestibility as a 3 %-unit change in aNDF for AH or a 4 %-unit change in aNDF for CS.

**NOVEL ALFALFA PRODUCTS**

Two important conditions must be met for alfalfa fractionation to be feasible and sustainable: 1) the total value of the resulting products must be greater than the original forage plus the cost of processing; and 2) all fractions must have an economic value to avoid creating a waste stream. Three methods of forage fractionation exist: 1) wet fractionation; separation into juice fraction and a fiber fraction, 2) dry fractionation; separation into leaves and stems, and 3) fractionation by passage of the whole herbage through the digestive systems of ruminant animals, leaving a high fiber residue.

Wet fractionation of forage crops allows biomass to be produced at very competitive prices due to the high values of the co-products. The fractionation process consists of expressing juice from fresh herbage (Koegel et al. 2000). The resulting fibrous fraction is high in cell wall constituents (cellulose, hemicellulose, and lignin). It is suitable for combustion, gasification, or enzymatic hydrolysis and fermentation to ethanol or organic acids (e.g. lactic) (Sreenath et al. 2001a, 2001b).

The juice fraction contains 25 to 30% of the dry matter in the original herbage depending on the severity of processing. It is high in protein and solubles and is almost fiber free. It can be used to produce both food-grade and feed-grade protein concentrates as well as other high-value products (xanthophylls for pigmentation poultry products; enzymes such as phytase, cellulas, lignin peroxidase and α-amylase and biodegradable plastics, all from transgenic alfalfas).

Koegel et al. (1999) reported feeding growing chicks with alfalfa-produced phytase, which at appropriate levels can totally replace the inorganic P supplementation. Replacing inorganic P with phytase resulted in a reduction of P concentration in poultry feces to less than one-half. They further reported that alfalfa phytase
in the form of fresh juice; dried juice or leaf meal was all-effective. The quantity of phytase, which can be produced in transgenic alfalfa is on the order of $200 \times 10^6$ units/acre/year, equivalent to an amount able to treat 500 tons of poultry ration. At current cost of inorganic P supplementation, the value of phytase would be $750 - $1500 per acre-year. The value of xanthophylls and protein content of alfalfa as well as the environmental benefits would be in addition to this.

**Dry fractionation of alfalfa hay.** Dry fractionation of alfalfa hay into leaf meal and stems used as the Minnesota Valley Alfalfa Producers (MNVAP), Granite Falls, Minnesota and Northern States Power (NSP), Minneapolis, Minnesota (Martin and Oelke, 1996), pioneered solid fuel. The research effort to produce 75 MW of electrical energy from alfalfa stems via gasification was initiated in 1993 by Department of Energy, University of Minnesota, MNVAP and several power generation partners. The project was cut short of construction of a new power generation plant in May 1999 due to negation of the original power purchase agreement between MNVAP and NSP. NSP was under legislative mandate to generate power from a closed-loop farm grown biomass system by 2002.

However, under pressure from businesses not willing to pay the alfalfa-electricity based energy prices, alfalfa processors claiming unfair research product support for MNVAP and unusual delays in approval of the power purchase agreement by the Public Utilities Commission the project were terminated (Sheaffer et al. 2000). However, animal feeding trials to investigate the use of alfalfa leaf meal (ALM) for dairy cattle, beef, and turkey feed supplement have been completed (DiCostanzo et al., 1999). Minnesota researchers (DiCostanzo et al., 1999) concluded that ALM is a suitable substitute for hay and soybean meal in diets of lactating dairy cows, although some question remains as to the performance and body weight response to ALM supplementation during a whole lactation. As a component of starter diets, ALM has the potential to enhance intake and gain when constituting 12% of the starter DM. At greater inclusion proportions, ALM may reduce intake in young ruminants. In dairy calves (aged 4 to 40 d), this reduction in intake may or may not be accompanied by a reduction in weight gain. The latter was the case when suckling calves were offered creep feed for 80 d before weaning. In receiving (growing beef animals after shipment) diets, DMI enhancement may not be accompanied by a gain response; thus, feed DM required/kg gain may increase. This effect does not appear to carry over into the finishing period. In fact, finishing steers fed 9% of their diet DM as ALM had faster gains at greater intakes. The most “adequate” inclusion level for ALM appears to be between 7 and 12% of the diet DM in beef cattle. Effects of ALM on incidence of liver abscess in feedlot diets are somewhat inconclusive and warrant further study. Similarly, efforts to enhance the value of ALM through heating to render a bypass protein source must focus on reducing exposure time or temperature.

While solid fuel yields the highest net energy and has the lowest processing cost, its use is generally limited to electric power generation. An alternative to solid fuel is the saccharification and fermentation of the ligno-cellulosic, fiber fraction to ethanol (Koegel et al., 1999). While conversion of fiber to ethanol results in less total energy and is a more complicated process, its versatility and potential use as a transportation fuel make it an interesting alternative. USDA scientists have identified a potential high value by-product from bacteria fermenting alfalfa fiber for ethanol in a sticky resin called material glycocalyx. Glycocalyx has potential to replace phenol-formaldehyde resin currently used in forming plywood panel.

**CONCLUSIONS**

Western dairy producers demand high quality alfalfa hay. Producers shift to harvesting alfalfa for silage to reduce risk of rain-damage and to increase harvest and storage mechanization. Alfalfa haylage has too much NPN to support protein needs of lactating cattle without expensive supplements or without cattle excreting excessive nitrogen in urine. Combining alfalfa hay or haylage and corn silage as at least 1/3 of each as the forage source improves cow performance and minimizes potential negative environmental impacts of excessive NPN in diets. Excessive NPN in alfalfa silage diets can be reduced by use of good silage management and addition of additives, which protect protein. Premium forage quality of alfalfa hay demanded by dairy operations may reduces yield; but research is needed to determine these discounts. New
value added products from alfalfa have potential for higher value than current alfalfa hay. Fractionation processes will be required to obtain value from new value added traits in alfalfa. The entire alfalfa industry must support public and private research to enable new alfalfa products to become part of the agricultural industry.

REFERENCES


