

ALFALFA: CROP FOR THE FUTURE

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ABSTRACT

Alfalfa use by dairy cattle has decreased in recent years because of excessive non-protein nitrogen and low fiber digestibility. Ideal attributes for plant modification of alfalfa may include those that increase milk potential per acre and/or per ton, enhance digestible NDF, improve protein content and amino acid balance, improve agronomic traits for insect protection (safer forage supply), herbicide tolerance, virus resistance, drought tolerance, cold tolerance, improved mineral availability and enhanced yield. Progress in attaining these attributes will accelerate with the use of biotechnology. Livestock and hay enterprises will benefit from alfalfa that is less prone to contain mycotoxins or toxic weeds, or to induce bloat; have improved nutrient utilization for milk and meat production; and produce less animal wastes resulting in improved efficiency, profitability, and a better environment. Value-added traits of alfalfa are needed to provide farmers new high value profitable products. Processing alfalfa to obtain value added products includes three different fractionation methods: 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. Phytase from transgenic alfalfa has been tested in poultry and swine rations. Alfalfa hay can be fractionated to yield stems and leaf meal. Alfalfa leaf meal has been shown to be acceptable supplement to replace a portion of alfalfa hay and soybean meal in diets of lactating dairy cattle, replace protein supplement in beef cow diets, finishing steer diets and diets of growing turkeys. The fiber portion of alfalfa can produce lactic acid, ethanol or a bioadhesives for use in plywood.

Key Words: alfalfa, protein, fiber digestibility, fractionation, transgenic, and Phytase

INTRODUCTION

In 2004 U.S. farmers harvested 24.7 million acres of alfalfa. Alfalfa hay and haylage yielded 83.9 million tons valued at \$8.4 billion, ranking behind only corn, soybeans and wheat. Alfalfa hay supports dairy, beef, sheep, and horse production in the U.S. as well as a growing export market. Alfalfa acreage has remained somewhat constant but hay production has declined in recent years. Alfalfa hay production is moving west with the rapid growth of the dairy industry. Dairy farm numbers are declining most rapidly in dairy regions of the Midwest. Beef cow-calf production remains relatively constant on U.S. farms. Farms with horse and ponies have increased as well as animal numbers (3.6 and 3.0 million, 2002 and 1997, respectively). Lactating dairy

cattle and horses require a range in qualities of alfalfa based on performance requirements; high-quality hay and haylage demands premium prices for dairy, but alfalfa with lower relative nutrient content demand equally high prices from horse owners. 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. Novel traits to improve alfalfa are available. Redesigning alfalfa to reverse declining amounts in diets and from acreages will improve alfalfa for other livestock uses. We will discuss new novel concepts being investigated with alfalfa, which have potential to increase acreage, add product value and offer new products. Major factors of increased utilization are yield enhancement, forage quality improvements, environmental enhancements, and new products.

ALFALFA UTILIZATION BY DAIRY CATTLE

High quality alfalfa is palatable and often maximizes intake and production of dairy cows. Alfalfa is low in fiber and high in protein compared to other forages, which makes it an excellent complement for grains and other forages in dairy rations. Although there are genetic differences in nutritional value among alfalfas, currently the nutritional quality of alfalfa is established primarily by harvest management. Although there are differences among seasons and cuttings, the composition and dry matter digestibility (DMD) of alfalfa is related to plant maturity. Alfalfa hay composition in Table 1 was derived from relationships among chemical components obtained from several data sets (Mertens, 1973; Onstad and Fick, 1983; Fick and Onstad, 1988) and analyses obtained from ten commercial forage testing laboratories that were used to develop standards for reporting hay market prices (Mertens and Getz, 2004). The crude protein, ash, crude fat, fiber, and lignin values in Table 1 agree with those of similar quality found in the Dairy NRC (2001). The forage quality descriptions in Table 1 are relative and may not reflect the economic or nutritional value of the alfalfa in a given situation. For example, exceptional quality hay as described in Table 1 may provide too much protein and not enough aNDF in a particular dairy ration and its value may not be exceptional. As with corn silage, a holistic approach for the specific dairy enterprise should be taken when selecting the traits for the ideal alfalfa.

Immature alfalfa is high in protein, but the protein is rapidly fermented in the rumen to ammonia and not used efficiently. Because alfalfa protein is used inefficiently, dairy rations containing predominantly alfalfa forage are formulated to contain 1 to 3 %-

units more protein. When used as the sole forage source, the high protein and low fiber concentrations in immature alfalfa can make it difficult to formulate rations that meet the protein, energy and fiber requirements of dairy cows. As alfalfa matures, the proportions of crude protein and NFC decrease. The main NFC in alfalfa is pectin of which 10 to 20% is not extracted by acid detergent causing the difference between aNDF and ADF to underestimate hemicellulose in alfalfa. Because pectin ferments rapidly and completely without a decrease in ruminal pH (Hatfield and Weimer, 1995), it may be desirable to maintain or increase its proportion in alfalfa because alfalfa is relatively deficient in rapidly fermentable carbohydrates when compared to corn silage.

Table 1. Typical composition (% of dry matter) of alfalfa hays varying in fiber content (adapted from Mertens, 2002).

Forage description	CP ^a	EE ^b	Ash	NFC ^c	Star ^d	Pec ^e	aNDF ^f	ADF ^g	ADL ^h
Exceptional quality	25.4	2.7	10.4	31.5	3.1	14.2	30.0	24.0	4.53
Very high quality	24.0	2.6	9.9	29.4	2.9	13.2	34.1	27.0	5.38
High quality	22.5	2.5	9.5	27.4	2.7	12.3	38.2	30.0	6.23
Good quality	21.0	2.4	9.1	25.3	2.5	11.4	42.2	33.0	7.08
Fair quality	19.5	2.2	8.7	23.2	2.3	10.5	46.3	36.0	7.93

^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

As in other forages, the proportions of fiber and lignin increase with maturity in alfalfa. Alfalfa fiber contains a high proportion of lignin relative to grasses resulting in low digestibility relative to grasses. Whereas, 60 to 80% of grass fiber is potentially digestible, the potential extent of digestion of alfalfa fiber is only 40 to 60% due to its high lignin content. However, alfalfa has a great advantage over grasses because the rate of digestion of its potentially digestible fiber is 2 to 3 times that of grasses. It also appears that the indigestible fiber in alfalfa disintegrates into particles that rapidly pass out of the rumen. The higher intake and digestibility often observed with alfalfa based diets compared to those containing grass is not due to greater digestibility of alfalfa fiber, but due to alfalfa's low fiber content and the rapid rates of digestion and passage of that fiber.

PROPORTION OF ALFALFA SILAGE AND CORN SILAGE

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, respectively. 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.

PLANT MODIFICATIONS OF ALFALFA

Over the past fifty years great advances have been made in the development of varieties with improved winter hardiness and pest resistance (insects, nematodes, and pathogens), providing even greater potential utilization in modern farming systems. To develop alfalfa varieties with physical and biochemical properties that fit the needs of the high producing dairy cow (i.e., greater cell wall digestibility, less protein degradation during ensiling, increased by-pass protein, increased yield without quality loss, insect and pathogen resistance, herbicide tolerance, reduced bloat, and winter hardiness) requires input from several disciplines. Strategies that embrace traditional genetic selection methods as well as precision breeding and other tools biotechnology may be needed in a timely manner to move a desirable trait into the elite germplasm in a timely manner. The goal is to have alfalfa varieties that can meet the needs of the dairy enterprise and at the same time maximize their use in farming systems that improve the ecological environment (N fixation, excellent nutrient sink, stand longevity, etc.). Developing alfalfa that could retain nutrition quality with few cuttings, increased yields, and better water use efficiency would be a major improvement in the profitability of alfalfa production.

ATTRIBUTES OF IDEAL ALFALFA

An ideal alfalfa would contain a better balance of protein and rapidly fermentable carbohydrate. At an optimum aNDF concentration of about 40% (DM basis), it would be desirable to have about 18% crude protein, less ash and about 30% NFC. It would also be beneficial to have a better balance of amino acids in the protein and with a slower rate of degradation in the silo or rumen to minimize its losses as ammonia. Increasing the fat to 4% might also be energetically advantageous to dairy cows. The rate of digestion and passage of alfalfa fiber is excellent when compared to other forages and nothing should be done to diminish these attributes. However, it might be desirable to improve the potential extent of fiber digestion by modifying lignin content or characteristics. For grazing or green chop purposes, removal or suppression of the bloat causing properties would be beneficial. Above all, the yield of alfalfa should be enhanced with a reduction in the number of cuttings needed to produce dairy-quality alfalfa forage.

Yield: Although quality has improved, alfalfa yield has not kept pace with corn. This is becoming more of an issue as land, labor, and energy costs continue to rise placing a greater burden on obtaining sufficient value from the harvested crop. Developing germplasm with greater pest resistance, improved winter hardiness and increased quality under a frequent cutting regime has made recent gains in yield. There would seem to be sufficient genetic diversity to select for much larger plants that would provide significantly higher yields per acre (JoAnn Lamb, personal communication), but forage quality cannot be sacrificed. There are other opportunities for improving total biomass production that involve specific tissues of the alfalfa plant such as leaves and stems.

Reducing leaf loss has potential for enhancing biomass and quality. One of the problems with large plants in a typical seeding pattern is the loss of leaves that are shaded in the lower portions of the crop canopy. A solution to the problem could involve genetic selection for increased leaf retention or possibly using a molecular approach to disable genes that are responsible for leaf drop. This would require identification of specific cell wall hydrolases involved in the disruption of cells in the attachment area of alfalfa leaves to the stem. For other plants it has been shown that cellulases and pectinases are critical for leaf drop. If plants could maintain leaves after they have passed senescence this would increase total biomass. The animal would readily utilize the digestible cell walls of leaves even though the senesced leaves would not contain much protein or soluble carbohydrate. Increasing the mechanical strength of leaf attachment may also improve harvest recoveries of leaves.

Harvesting techniques can greatly impact biomass recovery. Harvest losses with conventional hay-making equipment are typically in the range of 6 to 19 percent. Utilizing haylage versus hay probably has the greatest single impact both in terms of preserving total biomass and quality. Even though more alfalfa haylage is being

produced in the Midwest as a rain damage alleviator, production and marketing of haylage outside the dairy enterprise is difficult. There are technologies being developed such as hay maceration (US Dairy Forage Research Center) that will improve hay production to preserve biomass and improve quality at the same time. A macerator mat harvester could keep harvest losses well below the 6 to 19% loss (Koegel et al., 1992).

Weeds in alfalfa are a major challenge. They can inhibit successful stand establishment, reduce yields, lower forage quality, reduce stand life and be toxic to livestock. Current weed control products have a narrow window of application, relatively long preharvest intervals, risk crop injury, have requirements for soil incorporation, narrow weed control spectrum, and there are crop rotation restrictions. With the development of Roundup Ready[®] alfalfa, like other Roundup Ready crops, growers can spray alfalfa fields with Roundup herbicides to control more than 200 species of weeds without injuring the alfalfa crop or negatively affecting the quality of the forage. This product should be available for commercialization in 2006.

Fiber Digestibility: Fiber digestibility is an important component of forage having an impact on intake and digestibility by the dairy cow. Hatfield et al. (1999) provides background, on the molecular basis for improving forage digestibilities, Barrière et al. (2004) on the genetic and molecular basis of grass cell wall biosynthesis and degradability, and Ralph et al. (2004) on lignins. Lignin is a phenolic compound found in most plant secondary cell walls, is indigestible, and cross-links with other cell wall components resulting in decreased cellulose digestibility. Lignin content increases, and cell wall digestibility decreases as alfalfa plants mature. Almost every enzyme involved in the synthesis of lignin monomers has been investigated in one species or another (http://www.psb.ugent.be/research/molgen/lignin_details.htm) with variable impacts upon the concentration of the final lignin polymer deposited within the cell wall matrix. Some have had dramatic effects upon the total lignin (>50% reduction), but producing a phenotype that is fragile and with poor agronomic qualities. Dixon's group (Guo et al., 2001) at the Noble Foundation have altered the lignin pathway in alfalfa by decreasing the expression of two genes which are involved in the biosynthesis of coniferyl and sinapyl alcohol, the main building blocks of lignin. The changes in lignin were on the order of 20% reduction (Guo et al., 2001) that translated into increases in digestibility of 2-5%. This improvement can be compared to conventional breeding where over 15 years selection has resulted in a 2-3% increase in cell wall digestibility.

An alternative way to improve digestibility is to selectively increase specific carbohydrates that make up alfalfa cell walls such as pectin. Alfalfa stems typically contain 10-12% pectin as a component of the cell wall matrix. Pectic polysaccharides are rapidly degraded by rumen microbes producing acetate and propionate, but do not result in acidosis like rapidly fermented starch (Hatfield and Weimer, 1995). The US Dairy Forage Research Center has been involved with a consortium made up of alfalfa breeding companies to select for increased concentrations of pectin in alfalfa stems. Through two cycles of selection the total stem pectin concentration has been increased by 15-20% (Hatfield et al., unpublished data). Preliminary results indicate that in vitro total dry matter digestibility was increased. However, additional work must be done to

determine what other changes have occurred within the plant because an increase in one component requires the decrease in some other component. It is encouraging that selection can be made for specific cell wall components.

Alfalfa cell walls also contain xylans and cellulose with vastly different digestibilities (Hatfield and Weimer, 1995). The xylans in alfalfa stems (20-25% of total) have a slow rate and low extent of digestion. Replacing at least part of this cell wall fraction with another polysaccharide could have major impacts upon total fiber digestion. Increasing the cellulose content without increasing lignin should result in a wall matrix that has a greater extent of degradation. The impact of manipulating xylan or cellulase upon the function of the alfalfa plant is unknown at this time. Precision breeding techniques allow altering a gene and determining its impact in a relatively short period of time. In this way one can determine right away if altering a particular component is going to improve plant function or be detrimental. With the exception of cellulose, the genes involved in xylan and other cell wall polysaccharide biosynthesis have not been identified, which eliminates this approach as a way to test the hypothesis of altering specific polysaccharides. It may be possible to use this approach with cellulose; however, most plants appear to have relatively large families of cellulose synthase genes making this approach difficult.

Protein: The full benefit of alfalfa protein is not realized due to its poor utilization by the animal. Ruminal microbes degrade alfalfa protein too rapidly resulting in excessive excretion of nitrogenous waste by the animal. In addition, protein breakdown during ensiling can be extensive. This loss is due to plant proteases degrading 44 to 87% of forage protein into ammonia, amino acids and small peptides during silage fermentation resulting in losses of up to \$28 per acre for alfalfa. Decreasing protein degradation during the silage making process and in the rumen would decrease the need for supplemental protein and decrease the loss of nitrogen to the environment on the dairy farm.

Red clover has been found to have up to 90% less proteolysis than alfalfa during ensiling (Papadopoulos, 1983). This observation suggests that red clover should be an ideal legume for ensiling. Yet the widespread use of red clover is limited due to its poorer agronomic characteristics such as low stand persistency, yield, and its slow drying rate in the field. Lower extent of proteolysis is not due to differences in the inherent proteolytic activity in red clover versus alfalfa, but rather related to the presence of a soluble polyphenol oxidase (PPO) and *o*-diphenols in red clover (Jones et al., 1995a; Jones et al., 1995b; Jones et al., 1995c). This conclusion was initially based on several observations including: 1) red clover contains factors that can rapidly (<0.25h) inhibit proteolysis in both red clover and alfalfa, as determined by mixing experiments; 2) red clover leaves contain >250-fold higher levels of PPO activity than alfalfa leaves; 3) red clover contains abundant *o*-diphenol PPO substrates which are depleted as proteolysis is inhibited; 4) one of the factors involved in proteolytic inhibition is heat labile (consistent with involvement of a proteinaceous factor); and 5) proteolytic inhibition is O₂-dependent. Recently, the US Dairy Forage Research Center has been able to successfully test the hypothesis that PPO and *o*-diphenols inhibit proteolysis in

plant extracts. Researchers have further demonstrated the role of PPO in proteolytic inhibition in plant extracts using a transgenic alfalfa system.

Although alfalfa has at least one gene encoding PPO, expression has not been detected in any tissues except developing seedpods. Further, significant PPO activity in alfalfa leaves and neither stems nor significant amounts of *o*-diphenol substrates have been detected. Thus, alfalfa is an ideal model system to explore the role of PPO/*o*-diphenols in inhibition of post-harvest proteolysis. To demonstrate the role of PPO and *o*-diphenols in inhibition of proteolysis, a cloned red clover PPO gene (*PPO1*) was constitutively expressed in transgenic alfalfa (*PPO1*-alfalfa). Proteolysis was inhibited in leaf extracts of the *PPO1*-alfalfa when the *o*-diphenol caffeic acid was added (Sullivan et al., 2004), Figure 1. No inhibition was observed when caffeic acid was omitted. Substantial proteolysis was observed in leaf extracts of control alfalfa lacking a PPO transgene, even if caffeic acid was added to the extract, indicating that caffeic acid alone does not result in *in vitro* proteolytic inhibition. The extent of proteolytic inhibition seen for *PPO1*-alfalfa extracts with added caffeic acid was comparable to that seen for red clover extracts. These results clearly demonstrate the major role of PPO and *o*-diphenols in post-harvest proteolytic inhibition in red clover and that expression of the PPO gene in other forages can inhibit proteolysis when an appropriate *o*-diphenol is added.

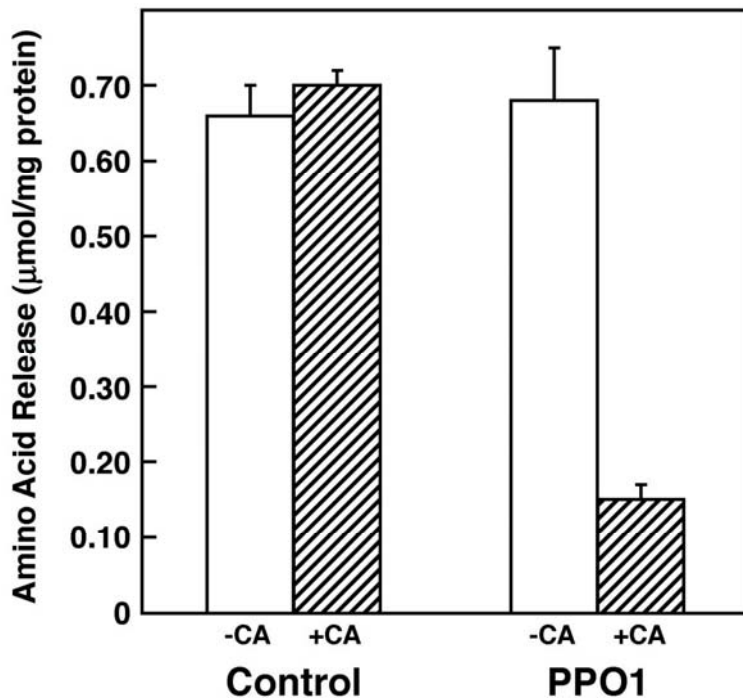


Figure 1. PPO inhibits postharvest proteolysis in an *o*-diphenol-dependent manner. Amino acid release during a 4-hour incubation at 37°C was used to measure proteolysis in extracts of control or *PPO1*-expressing alfalfa as indicated in the presence (+CA) or absence (-CA) of 3 mM caffeic acid. (Sullivan et al., 2004).

Slowing the rate of alfalfa protein degradation in the rumen is difficult to address from the alfalfa plant. There is some evidence that PPO generated *o*-quinones interact with proteins in red clover providing some protection in the rumen creating greater bypass protein. It is clear that tannins provide protection of plant proteins from ruminal degradation. Tannins are phenolic

compounds that generally bind with proteins, decreasing the rate and extent of protein digestion. Forage legumes (e.g. birdsfoot trefoil) that produce tannins in leaves or stems have increased stability of the protein in the rumen, thus more protein escaping degradation in the rumen. Unfortunately, alfalfa does not produce tannins except in the seed coats. With new knowledge about tannin biosynthesis (Dixon group, Noble Foundation) it may be possible to engineer alfalfa to produce tannins that provide protein protection in the rumen and may also lead to less bloat. The plant is already producing many of the “raw materials” needed to produce the building blocks of tannin polymers; it’s just a matter of diverting some of these into a new pathway. Another approach is to have alfalfa produce proteins containing increased concentrations of sulfur containing amino acids whereby more disulfide bonds are present which are known to be less degradable in the rumen. Tabe et al. (1995) used a biotechnological approach to insert a gene from a sunflower plant into alfalfa that resulted in the production of a sunflower seed storage protein, rich in cysteine and methionine, in alfalfa leaves.

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 pigmenting poultry products; enzymes such as phytase, cellulases, 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 200×10^6 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.

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.

CONCLUSIONS

Alfalfa is a key forage dairy, horse and beef operations. Enhancing the nutrient utilization of alfalfa in dairy diets offers potential new products and expanded acreage. Past progress relying on traditional breeding has been slow in enhancing the quality and attributes of forages. With the recent tools of biotechnology, rapid advancement in forages with improved agronomic and nutritional traits may be possible leading to more efficient and environmentally friendly dairy enterprises.

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