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Maximizing utilization of alfalfa protein: The example of the lactating dairy cow

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SUMMARY – Forages help meet the absorbed protein requirements of ruminants by providing degraded CP for microbial protein synthesis plus protein that escapes rumen degradation. Evidence from numerous feeding studies with lactating dairy cows indicates that excessive rumen protein degradation makes absorbed protein the most limiting nutritional factor in higher quality temperate legume forages, especially alfalfa. Extensive NPN formation in ensiled alfalfa depresses protein utilization. Techniques that reduce NPN formation in the silo, such as field wilting or acid treatment will enhance protein value to the lactating cow. However, more effective means of reducing NPN in alfalfa silage are needed. The CP in alfalfa harvested as hay, rather than silage, is used more efficiently by lactating cows; degraded CP from hay is captured more efficiently by rumen microbes for protein synthesis *in vitro*. Maximizing concentrate intake without over feeding will stimulate microbial utilization of degraded protein in the rumen. Supplementation of alfalfa based diets with high "bypass" proteins has resulted, in some cases, in substantial increases in milk production with cows in early lactation. New and better approaches will be required if ruminants are to make optimal use of the protein in alfalfa forages.

Key words: *Medicago sativa,* conservation methods, ruminal proteolysis, milk yield, milk quality.

RESUME – *"Maximiser l'utilisation des protéines de luzerne : L'exemple de la vache laitière". Les fourrages contribuent aux besoins en protéine absorbée des ruminants en procurant des matières azotées totales (MAT) dégradées pour la synthèse de la protéine microbienne plus la protéine qui échappe de la dégradation du rumen. Beaucoup d'études sur la vache laitière ont prouvé que l'excessive dégradation de la protéine dans le rumen fait que la protéine absorbée soit le facteur nutritionnel le plus limitant chez les légumineuses fourragères tempérées de plus haute qualité, spécialement la luzerne. La formation d'azote non protéique (ANN) excessif dans la luzerne ensilée limite l'utilisation de la protéine. Les techniques qui réduisent la formation de ANN dans l'ensilage telles que le préfanage dans le champ ou le traitement par acide amélioreront la valeur des protéines pour la vache laitière. Cependant, on a besoin de moyens plus efficaces pour la réduction de ANN chez la luzerne ensilée. Les MAT de la luzerne récoltée comme foin plutôt qu'ensilée, sont utilisées d'une forme plus efficace par la vache laitière ; la MAT dégradée du foin est fixée plus efficacement par les microbes du rumen pour la synthèse de la protéine* in vitro. *La maximisation de l'ingestion de concentré sans suralimentation encouragera l'utilisation microbienne de la protéine dégradée dans le rumen. Les régimes basés sur la supplémentation de luzerne avec protéines "bypass" ont donné comme résultat, dans quelques cas, des augmentations substantielles de la production de lait chez des vaches au début de la lactation. De nouvelles et meilleures façons seront nécessaires pour arriver à l'utilisation optimale des protéines de la luzerne par les ruminants.*

Mots-clés **:** Medicago sativa*, méthodes de conservation, protéolyse ruminale, production de lait, qualité du lait.*

Introduction

Dairy cattle and other ruminants meet their requirements for absorbed protein from protein synthesized by the microbes in the rumen plus feed protein that escapes degradation by these same organisms. Digestion in the abomasum and small intestine of absorbed protein originating from the mixture of feed protein escaping the rumen (so-called "bypass" protein) plus microbial protein supplies the amino acids needed by the animal. Compared to nonruminants, ruminants make efficient use of diets with low protein content, or poor protein quality, because microbial protein formation in the rumen captures recycled urea that would otherwise be excreted in the urine. Moreover, microbial protein has a good amino acid pattern that will supplement or complement poor quality dietary proteins. However, ruminants make relatively inefficient use of diets with high protein content or high quality. Many feed proteins are degraded by rumen microbes at rates that exceed the rates at which the organisms resynthesize protein from the peptides, free amino acids and ammonia produced in protein breakdown. Protein degradation products not incorporated into microbial protein are largely catabolized to ammonia;

ammonia may build up to high concentrations in the rumen. Excess ammonia "overflows" from the rumen, being carried via the blood to the liver where it is taken up and converted, at some energy cost to the animal, to urea that is largely excreted in the urine.

The genetic selection that has so markedly improved the milk production potential of the World's dairy cattle has led to correspondingly large increases in requirements for absorbed amino acids to synthesize milk components. Heretofore, it has been profitable to feed very large amounts of protein, either as conventional protein supplements or as more costly high bypass proteins – despite diminishing returns on protein utilization – because the value of the extra milk and protein produced was greater than the extra feed cost. Increasingly, dairy farmers have been caught in a cost-price squeeze; decreasing purchases of expensive protein supplements would improve profitability. Growing legume forages, especially alfalfa, represents a cost-effective way of providing inexpensive sources of dietary CP. However, substantial evidence indicates that the protein in alfalfa forage is particularly susceptible to microbial breakdown in the rumen and alfalfa protein is often poorly utilized by dairy cows. Amounts of degraded protein recaptured as microbial protein are related to the dietary content of fermentable energy rather than protein, and alfalfa forage is generally lower in energy than concentrates. There is a strong trend toward increased feeding of alfalfa silage to dairy cows. This trend makes worse the problem of improving utilization of alfalfa protein. This review will emphasize recent evidence obtained at our Center and in other research defining the magnitude of the problem, outlining approaches for dealing with it using current methods and suggesting ways for improving alfalfa utilization in the future. A discussion of this topic was published earlier (Broderick, 1995a).

Evidence of poor utilization of protein in alfalfa forage

In research designed to study forage energy content, lactating cows were fed alfalfa silage, alfalfa hay, or two levels of corn silage (Broderick, 1985). Feeding diets with about 60% of DM from alfalfa forages or corn silage resulted in similar yields of milk and fat (Table 1). Milk yield was lower when corn silage was fed at 76% of DM, even though that diet provided more NEL (and ME) than the alfalfa diets (NRC, 2001). However, cows fed alfalfa silage or hay produced milk with lower protein content than cows fed corn silage-based diets that were supplemented with solvent SBM to equalize dietary CP. The proportion of dietary CP intake secreted as milk protein, was 10% greater on 60% corn silage; N loss in excreta was lowest on this diet. Part of this effect was likely mediated by greater rumen fermentability of the corn silage diet which yielded greater microbial protein. However, utilization of the protein in alfalfa forages was lower than that in solvent SBM, which is known to be extensively degraded in the rumen (NRC, 2001).

Table 1. Effect of feeding alfalfa silage (AS), alfalfa hay (AH), or corn silage (CS) as the sole forage in the diet of lactating cows (Broderick, 1985)[†]

Item	63% AS	60% AH	60% CS	6% CS	SE
Diet CP (% of DM)	7.7	16.5	16.5	16.7	...
Diet NEL[††] (Mcal/kg of DM)	1.50	1.49	1.67	1.60	...
DM intake (kg/d)	24.1	24.0	23.1	23.9	0.6
NEL intake (Mcal/d)	36.2	35.8	38.5	38.1	...
Milk (kg/d)	29.8 a	29.4 ab	30.3 a	28.0 b	0.6
Milk fat (%)	3.68	3.70	3.86	3.84	0.11
Milk fat (kg/d)	1.09 ab	1.08 ab	1.14 a	1.05 b	0.02
Milk protein (%)	3.11 b	3.11 b	3.32 a	3.33 a	0.04
Milk protein (kg/d)	0.92 b	0.91 b	0.99 a	0.91 b	0.02
Milk-N/N-intake	0.211	0.225	0.254	0.223	...

[†]Percentages are the proportion of dietary DM coming from the respective forages.
[††]NEL contents of diets recalculated using the equations of Mertens (1987) to compute NEL in alfalfa forages and corn silage from NDF concentrations.
[a,b]Means in rows having different superscripts differ ($P < 0.05$).

Lactation studies were conducted at the Dairy Forage Center to test the hypothesis that the supply of protein rather than energy limits milk production in cows fed high-quality alfalfa. Dhiman *et al.* (1993) fed multiparous cows: (1) a standard diet – 49% alfalfa silage, 34% high-moisture corn, and 16% solvent SBM, 1% mineral-vitamin mix (49:50 F:C); (2) an all silage diet plus minerals and vitamins (All Forage); or (3) diet 2 supplemented with absorbable protein by abomasal infusion of 1.0 kg/d of casein. As expected, production was greatest in cows fed diet 1. However, compared with diet 2, cows infused with casein yielded 6.9 kg/d more milk and 180 g/d more protein. If energy were the first-limiting nutrient, then a large increase in milk yield with infusion of casein would not have occurred. Cadorniga and Satter (1993) quantified milk yield response on alfalfa silage-based diets with supplemental energy (23% of DM as high-moisture corn) or undegraded protein (23% of DM as expeller SBM). Positive and negative controls corresponding to diets 1 and 2 of Dhiman *et al.* (1993) also were fed. Milk yield was greater on all three supplemented diets than on the all forage diet; milk yield was similar for cows fed the positive control (49:50 F:C) and 23% expeller SBM, but lower on the diet with 23% high-moisture corn (Fig. 1). Yields of fat and protein on all four diets paralleled milk yields.

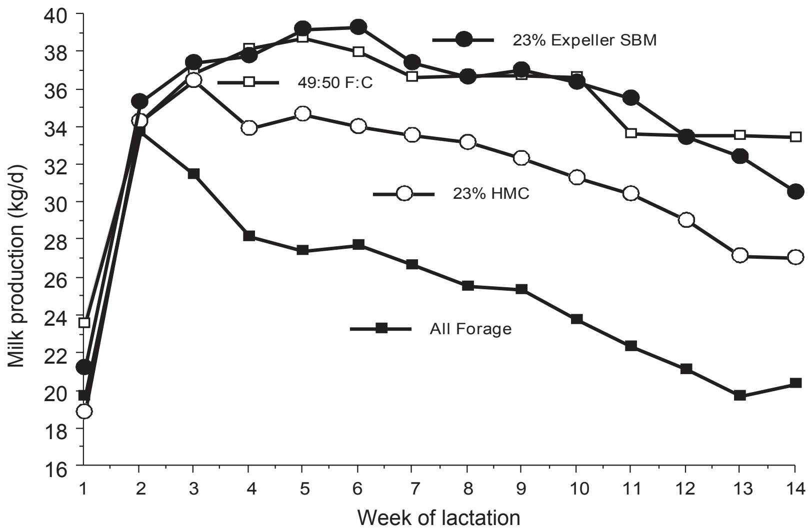

Fig. 1. Effect on milk yield of adding energy (as high moisture corn; HMC) or protein (as expeller SBM) to an all alfalfa diet (Cadórniga and Satter, 1993).

Greater response to undegraded protein than to energy supported the view that protein supply to the intestine limited production of dairy cows fed large amounts of alfalfa silage.

A series of five trials compared the milk protein response of lactating dairy cows to resistant protein from either expeller SBM (Broderick *et al.,* 1990) or fish meal (Broderick, 1992) fed to supplement diets containing (DM basis) 56 to 70% alfalfa silage plus high moisture corn. Response was computed as the increase in milk protein yield with supplemental CP, compared with negative control (alfalfa silage plus high moisture corn only) and setting response to solvent SBM at 1.0. Relative response to expeller SBM in three trials was 1.48 (i.e., a mean increase in protein yield 48% greater than that with solvent SBM). The mean relative response to low-solubles fish meal in two trials was 2.07. Mean relative response in one trial to high-solubles fish meal was 1.56, similar to expeller SBM. In another study, Voss *et al.* (1988) fed 30 multiparous cows a pretreatment diet from days 4-13 postpartum (covariate period), then switched cows for 60 days to one of two diets containing 55% alfalfa silage and 45% concentrate (DM basis) with either solvent SBM or roasted soybeans. These soybeans had been heated to 146ºC then held at approximately 120-125ºC for three hours before cooling. Feeding roasted soybeans substantially increased milk yield compared to solvent SBM. Roasted soybeans provided both more by-pass protein as well as more energy from oil so it was not possible to conclude that this production response was due solely to additional protein bypass. A follow-up study (Faldet and Satter, 1991) was conducted comparing solvent SBM, raw soybeans (Raw-SB), and roasted soybeans (RSB). Again, the soybeans were heated to 146ºC then held at about 120-125ºC, but this time for only one-half hour. Forty-six multiparous lactating cows were assigned sequentially to one of the three diets on day 15 of lactation, remaining on treatment through week 17 lactation. Each of the three diets contained (DM basis) 50%

alfalfa silage and 50% concentrate; concentrate consisted of ground shelled corn, vitamin-mineral mix plus one of the three protein supplements (10% SBM, 13% Raw-SB or 13% RSB). All diets were formulated to 19% CP and were fed as total mixed rations. Milk production responses are shown in Fig. 2. The diet supplemented with RSB, although containing the same amount of energy as the diet with Raw-SB, supported an average 4.7 kg/d greater milk production. There was little difference in production on SBM and Raw-SB, indicating the benefit from roasted soybeans in the first trial (Voss *et al.,* 1988) was due to increased protein bypass.

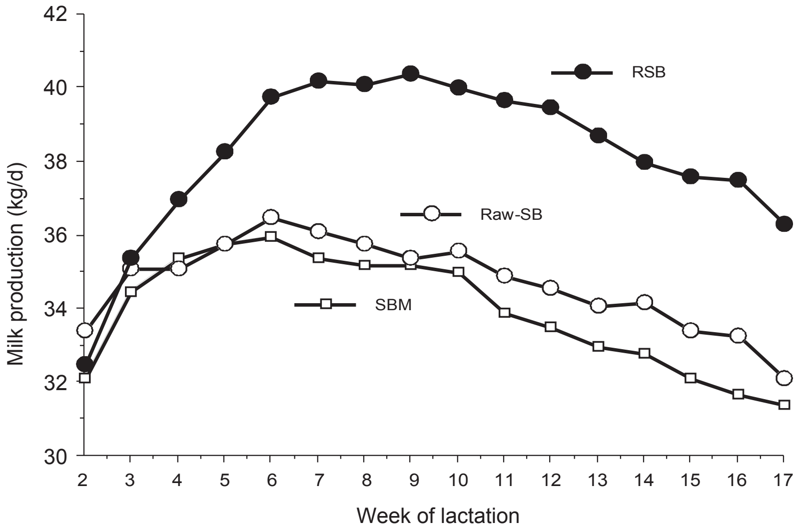

Fig. 2. Mean daily milk yield of cows supplemented with soybean meal (SBM), raw soybeans (Raw-SB), or roasted soybeans (RSB) (Faldet and Satter, 1991).

If heated appropriately, the rumen undegraded protein (RUP) content of alfalfa can be increased similar to heating protein concentrates. Forage DM content at time of ensiling has substantial influence on protein utilization via effects on heating in the silo. Intestinal flow and digestion of nonammonia N (NAN) was measured in cows fed diets containing 35% of DM from concentrate plus 65% from alfalfa conserved as silage at three different DM levels (Merchen and Satter, 1983). Feeding alfalfa silage containing 29, 40, or 66% DM resulted in NAN digestion in the small intestine equivalent to 43, 44, or 59% of the CP intake. Roffler and Satter (1985) compared alfalfa ensiled at 44% DM (high-moisture) or 64% DM (low-moisture) to dehydrated alfalfa by measuring effect of diet on blood concentration of branch-chain amino acids (BCAA), an indicator of amino acid uptake from the intestine (Bergen, 1979). Yearling heifers were fed (DM basis) 20% corn grain and 80% forage. Increasing alfalfa from 0 to 80% of dietary DM (by replacing corn silage) increased blood BCAA by 74, 227 and 298 nmol/ml when high-moisture silage, low-moisture silage, and dehydrated alfalfa were fed. This indicated that dehydrated alfalfa, which is heated extensively during processing, and low-moisture silage, which undergoes more heating and less proteolysis in the silo than high moisture silage (Muck, 1991), supplied more intestinally absorbable amino acids. Steam heating alfalfa hay for 47 min at 100-110ºC also reduced rumen protein degradability, although energy digestion was depressed (Broderick *et al.,* 1993). Feeding this hay as the only forage decreased milk yield in cows fed a diet with 81% alfalfa DM. However, feeding the steam heated hay to replace unheated hay or alfalfa silage at approximately 25% of dietary DM increased DM intake and yield of milk and milk components. Milk yield in cows fed the heated hay diet, which had 17% CP, was comparable to that of cows fed a diet with solvent SBM containing 23% CP. Alfalfa may be more sensitive to overheating than soybeans but controlled heat treatment of hay was useful for reducing rumen protein breakdown.

If proteolysis and NPN formation in the silo can be reduced, then forage protein utilization in lactating dairy cows will be improved. Charmley and Veira (1990) suppressed proteolysis in ensiled alfalfa by a 2-min steam-treatment, followed by inoculation to allow normal fermentation. This treatment did not alter NDF or ADIN content but significantly reduced NPN and increased NAN and microbial N flow at the small intestine (Fig. 3).

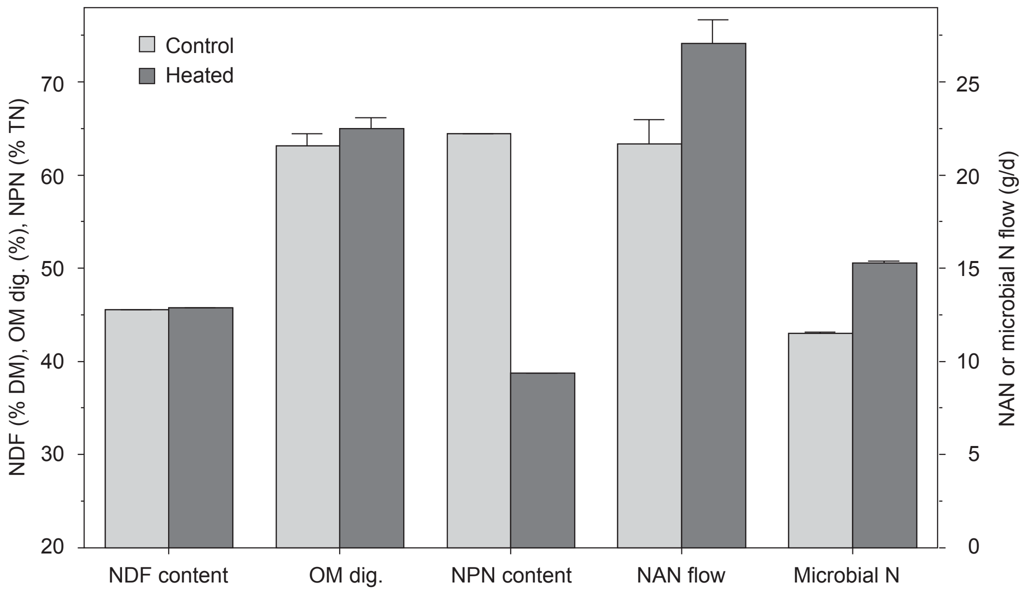

Fig. 3. Effect of feeding control alfalfa or steam-treated alfalfa silage on forage composition and abomasal flows of NAN and microbial N in lactating dairy cows (Charmley and Veira, 1990).

Although this treatment would not be practical for commercial silage making, a clear advantage was shown for reducing proteolysis in the silo. Nagel and Broderick (1992) wilted third-cutting alfalfa to 38% DM and ensiled it as untreated control (C), or treated with 8.2 L/ton formic acid (F) or 6.3 L/ton of a commercial product containing 16% formaldehyde (G). Reduced silage NPN indicated that treatments G and particularly F decreased proteolysis in the silo. Multiparous cows were fed diets containing 98.5% of DM from one of the three silages, plus minerals, vitamins, and a ketosis preventative. Compared with C, yield of milk and fat was increased 3.3 kg/d and 200 g/d with F and G; protein secretion increased 110 g/d on F and 60 g/d on G. This was interesting because European workers have reported that, although useful for direct-cut silage, formic acid has been found ineffective when applied to wilted silage (McDonald *et al.,* 1991). Vagnoni *et al.* (1997) found that acidifying alfalfa ensilage to pH 4 using either formic or sulfuric acids reduced NPN content of the silage produced from about 60% to about 40% of total N. The NPN content of commercial alfalfa silage typically is 55 to 60% of total N (Luchini *et al.,* 1997) and formic acid treatment usually suppresses NPN formation by about one-third (Muck, 1987). However, Vagnoni *et al.* (1997) also reported that treating alfalfa with trichloroacetic acid, which not only acidified ensiled material to pH 4 but virtually stopped proteolysis, reduced final NPN content to only 25% of total N. Although feeding silage with trichloroacetic acid may be harmful to the animal, this treatment showed the substantial potential for further reduction of NPN formation in alfalfa silage.

Red clover yields a silage with 30 to 40% less NPN than ensiled alfalfa (Albrecht and Muck, 1991). This effect results from the action of the polyphenol oxidase enzyme system in red clover that inhibits the plant's proteases in the silo (Jones *et al.,* 1995). We conducted several feeding studies comparing red clover and alfalfa silages harvested at similar maturities (Broderick *et al.,* 2000; Broderick *et al.,* 2001). Harvested in this way, red clover silage had about equal NDF content, but between 2 and 5 percentage units less CP in the DM, than alfalfa silage. Generally, DM intake was lower on red clover than alfalfa but overall milk and protein yields, although lower in two of five trials, were not nearly as depressed as DM intake. Digestibility of DM, organic matter and NDF were substantially greater on red clover than alfalfa. Compared to alfalfa silage, the lower CP content and lower DM intake, with generally similar milk and protein yields, gave rise to substantially greater feed and N efficiencies for red clover silage. Hoffman *et al.* (1997) reported similar DM intake and milk yields with the feeding of red clover and alfalfa silages to lactating dairy cows.

Approaches for improving utilization of alfalfa protein

Although very similar RUP values are reported for alfalfa hay and silage, indeed for hay-crop forages in general (NRC, 2001), lower rumen ammonia suggested there may be better microbial utilization of degraded CP in cows fed alfalfa hay (Broderick, 1985). Therefore, performance of lactating cows fed all their forage as either alfalfa silage or hay was compared in two trials in which alfalfa provided 67% of dietary DM (Broderick, 1995b). Protein adequacy of the basal diets was assessed from the response of cows to 3% fish meal in dietary DM: greater milk and protein yield with fish meal was taken to indicate that the corresponding diet without fish meal provided less absorbed protein. Alfalfa harvested for the first trial was from second-cutting and contained 35% NDF; silage had 21% CP and hay 19% CP. In the second trial, alfalfa was from first-cutting; silage and hay contained, respectively, 20 and 17% CP and 40 and 41% NDF. Lower CP in hay reflected the typically greater leaf loss occurring during hay versus silage harvest (Nelson and Satter, 1992a). Mean NPN contents were 52% (silage) and 8% (hay) of total N in both trials. Mean performance data from the two trials are in Table 2. Cows had lower DM intake and lost weight when fed silage without fish meal. Fat yield was lower on the silage and hay diets than on silage plus fish meal; yield on hay plus fish meal was intermediate. Yields of protein and SNF were lower on silage without fish meal than on the other three diets; fish meal increased mean protein yield 100 g/d on silage but only 30 g/d on hay. Greater energy digestibility in silage (Nelson and Satter, 1992b) may account for the increased milk yield, after correction of protein inadequacy with fish meal, because apparent digestibility of DM, NDF and ADF was greater on silage. Results from in vitro studies on samples of the same forages fed in these two trials (Peltekova and Broderick, 1996) indicated that silage and hay had similar RUP values, as indicated in NRC tables (2001), but that microbial protein synthesis was 29% greater on alfalfa hay. A third trial was conducted using the same protocol except that 50% of dietary DM was either alfalfa silage or hay; responses to fish meal again were 100 g/d more milk protein in cows fed silage and only 30 g/d in cows fed hay (Vagnoni and Broderick, 1997). Greater urinary excretion of purine derivatives on hay than silage suggested that there was greater formation of rumen microbial protein on the alfalfa hay diet. Taken overall, these findings indicate that there is more efficient capture of the degraded protein from alfalfa hay than alfalfa silage.

Table 2. Effect on intake, body weight gain, and milk production of supplementing diets containing alfalfa silage or hay with fish meal (Broderick, 1995b)[†]

Item	AS	AH	AS+FM	AH+FM	Prob.[††]
DM intake (kg/d)	22.3 b	24.0 a	23.3 ab	24.2 a	< 0.01
Body weight change (kg/d)	-0.39 b	0.45 a	0.08 ab	0.49 a	< 0.01
Milk (kg/d)	35.3 b	36.1 ab	37.4 a	36.9 a	0.02
Fat (%)	3.44	3.28	3.42	3.31	0.41
Fat (kg/d)	1.20 b	1.18 b	1.28 a	1.22 ab	0.02
Protein (%)	2.96 b	3.05 a	3.06 a	3.07 a	0.01
Protein (kg/d)	1.04 c	1.10 b	1.14 a	1.13 ab	< 0.01
SNF (%)	8.54	8.57	8.56	8.62	0.39
SNF (kg/d)	3.01 c	3.09 b	3.20 a	3.18 a	0.01
Milk-N/N-intake	0.268	0.289	0.257	0.269	...

[†]AS = Alfalfa silage, AH = alfalfa hay, FM = fish meal, SNF = solids not fat.

[††]Probability of a significant treatment effect.

[a,b,c]Means in rows having different superscripts differ ($P < 0.05$).

Providing sufficient fermentable energy for stimulating microbial capture of degraded protein appears to be particularly critical on alfalfa silage diets. Dhiman and Satter (1997) randomly assigned 45 multiparous and 29 primiparous cows at calving to one of three diets in a complete lactation study. Cows were fed 50% forage and 50% concentrate (DM basis). Forage was: (1) all from alfalfa silage; (2) 2/3 from alfalfa silage and 1/3 from corn silage; or (3) 1/3 from alfalfa silage and 2/3 from corn silage. Dietary NEL was kept equal by greater fat supplementation of alfalfa silage diets, but rumen fermentable energy presumably was greater with higher levels of corn silage. Dietary CP content was in proportion to alfalfa silage content: 18.6, 17.5 and 16.6% in diets 1, 2, and 3, respectively. Milk yield was numerically greatest for both multiparous and primiparous cows on diet 2 (2/3 alfalfa silage and 1/3 corn silage); yield on diet 2 for multiparous cows was 577 and 146 kg of milk/lactation greater than on diets 1 and 3, respectively. The difference in milk yield between diets 1 and 2 was significant ($P < 0.05$). Rumen ammonia was lower on both corn silage-containing diets. These results indicated that energy may be limiting on diets high in alfalfa silage and that diluting alfalfa silage with corn silage such that dietary CP was 1 or 2 percentage units lower did not reduce milk yield.

Feeding greater amounts of nonstructural carbohydrates and processing of grains to increase rumen fermentability will often improve N utilization on alfalfa-based diets. Note that when high concentrate diets are fed to lactating dairy cows, dietary fiber should be maintained at approximately 28% NDF to prevent low rumen pH and rumen dysfunction. Ekinci and Broderick (1997) found that grinding of high moisture ear corn (HMEC) through a 10 mm screen, which reduced mean particle size from 4.3 to 1.7 mm, significantly improved *in vitro* ammonia uptake, and presumably protein synthesis, by mixed rumen microbes. Compared to unprocessed HMEC, milk and protein yields were 2 kg/d and 120 g/d greater when cows were fed the ground HMEC to supplement diets containing 53% alfalfa silage. Feeding the ground HMEC also significantly decreased rumen pH and ammonia, and increased concentrations of total VFA. Valadares *et al.* (2000) diluted dietary alfalfa silage with increasing proportions of concentrate based on ground high moisture ear corn. Four diets containing (DM basis) 80, 65, 50 and 35% alfalfa silage and 20, 35, 50 and 65% concentrate were fed to lactating cows in a 4 4 Latin square trial with 3-week periods. Diets were maintained isonitrogenous by adding urea with increasing high moisture corn. Results indicated that there was no significant carry-over despite the short periods used in this trial. The response of three production traits to increasing dietary concentrate is shown in Fig. 4. In addition to the quadratic responses shown for yield of 3.5% fat-corrected milk (maximal at 57%) and DM intake (maximal at 51% dietary concentrate), quadratic responses were observed for NDF and ADF intake (maximal at 25 and 27%), fat yield (maximal at 43%), and feed efficiency (minimal at 27% dietary concentrate). However, yields of milk, protein, lactose and SNF were linear, not reaching a maximum even at 65% dietary concentrate. Microbial protein formation in the rumen, as estimated in this study from urinary excretion of purine derivatives, increased linearly with dietary concentrate level (Valadares *et al.,* 1999). The negative effects of over-feeding of concentrate clearly would be muted in a short-term trial of this type. However, the fact that, except for fat, yield of milk and milk components continued to increase with increasing energy density emphasizes the great nutrient requirements of the high producing dairy cow. These results show the importance of maximizing intake of fermentable carbohydrate, when this is economical, to optimize utilization of the CP in alfalfa forage.

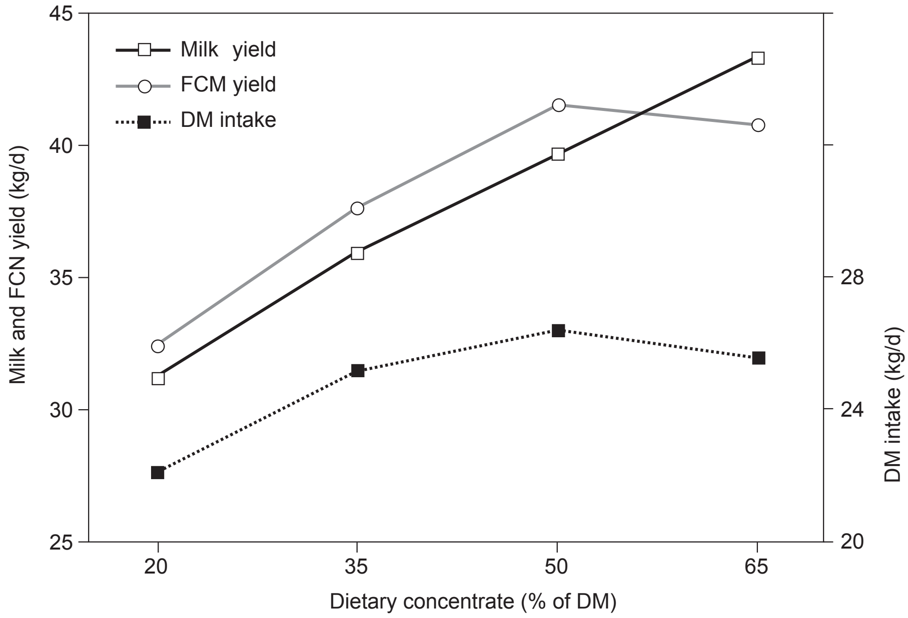

Fig. 4. Effect of DM intake and yield of milk and 3.5% fat-corrected milk (FCM) of replacing dietary alfalfa silage with increasing amounts of dietary concentrate (Valadares *et al.,* 2000)

There is a substantial body of literature showing the responses of lactating cows to grain processing and source as the means for maximizing utilization of RDP in alfalfa and other forages. A few examples are given here. In their review, Theurer *et al.* (1999) reported that steam-flaking corn and sorghum grain increased NEL contents by 20% compared to the dry ground grains; production and notably microbial protein synthesis in the rumen were improved with feeding of steam-flaked grains. However, this method of processing did not improve digestibility of wheat and barley starch (in one trial testing each grain). Keady and coworkers have reported on the advantages of supplementing dairy cows fed grass silage with starchy concentrates (Keady *et al.,* 1998) and sucrose (Keady and Murphy, 1998). One would expect similar effects for these carbohydrates sources with the feeding alfalfa silage as the principal forage.

Most of the research summarized above was from trials conducted with alfalfa silage and hay. *In vitro* studies have shown that the protein in freeze-dried alfalfa foliage was more degradable than that in the same alfalfa harvested as hay (Broderick *et al.*, 1992). This suggested that reducing rumen protein degradation in grazed forages might be even more advantageous than in harvested forages. Rogers *et al.* (1980) reported that supplementing lactating cows fed fresh cut ryegrass-white clover herbage with 1.0 kg/d of formaldehyde-treated casein increased milk, protein and fat yields by 2.0, 0.07 and 0.05 kg/d, respectively. These responses were similar to those obtained with fishmeal supplementation in the trials discussed above in cows fed alfalfa silage. Both Carruthers *et al.* (1997) and Stockdale (1999) reported that the effect on milk yield of feeding concentrate supplements to cows grazing alfalfa was largely a function of their energy content.

New developments in mechanization may improve forage harvesting as hay Koegel *et al.* (1988) developed an alternative hay-making process involving maceration (extensive shredding) of herbage prior to forming it into thin forage mats that were field-dried. Drying rates of the shredded alfalfa mats were three times that for conventionally harvested alfalfa hay (Koegel *et al.,* 1988); this would substantially improve chances of harvesting alfalfa hay without weather damage. Ruminants derived approximately 15% more energy from shredded than conventional alfalfa forage (Hong *et al.,* 1988). Shredded hay also had a somewhat greater RUP value as estimated from *in vitro* incubations (Yang *et al.,* 1993). We speculate that this resulted when soluble sugars, released with herbage cell rupture, were spread over the surface of the plant material, thus enhancing the Maillard reaction between protein and sugars during field drying. A series of lactation studies with alfalfa macerated prior to ensiling using a commercial prototype machine indicated that milk yield and feed efficiency were improved only about 5% versus control alfalfa silage (Broderick *et al.,* 1999). However, it appeared that this prototype machine was less vigorous in its mechanical action on the alfalfa plant (R.G. Koegel, pers. comm.).

Degradation rates and rumen escapes were estimated using in vitro procedures for a number of dried legumes forages that differed mainly in tannin concentration (Broderick and Albrecht, 1997). Rumen degradation of certain high tannin forages were much slower than alfalfa forage: sainfoins and lespedezas, the two highest tannin species tested, yielded degradation rates and estimated escapes ranging from 0.03 to 0.05/h and 53 to 61%, versus 0.20-0.25/h and 19-22% for alfalfa. All tannin-containing forages tested had slower degradation rates and greater escapes than alfalfa. The CP in red clover, a forage which has no detectable tannins, also was found to be less degradable than that in alfalfa, both in experimental silos (Albrecht and Muck, 1991) and in the rumen *in vitro* system (Broderick and Albrecht, 1997). Limited attempts to grow alfalfa in co-culture with high tannin forages has not consistently produced forage with reduced protein degradability or silage with lower NPN content (R.E. Muck, pers. comm.). Much of this difficulty may have been due to agronomic incompatibility of alfalfa and the other forages. Small differences in protein degradability were detected among alfalfa germplasm (Broderick and Buxton, 1991) suggesting that it may be possible to select alfalfa for reduced rumen protein degradation.

Conclusions

Inefficient utilization of alfalfa CP, particularly the high amounts of NPN in alfalfa silage, plus the high protein supplementation that this inefficiency necessitates, leads to poor CP utilization and excessive N excretion. Lowering protein breakdown to NPN in the silo would improve utilization of alfalfa silage CP; however, practical, cost-effective methods for reducing NPN in alfalfa silage currently are lacking. Certain forages such as red clover yield silage with reduced NPN; although promising, red clover silage has not yet proven to be an effective substitute for alfalfa. Feeding greater amounts of concentrate, particularly more finely processed grains (so long as adequate dietary content of effective fiber is maintained), will help maximize utilization of silage NPN. Often, feeding of high producing dairy cows necessitates finding the maximum amount of concentrate that can be fed without sacrificing fat test and animal health. The very low NPN content of alfalfa hay, and rates of protein degradation that are more synchronous with microbial growth, increases the efficiency of microbial protein formation in the rumen when alfalfa hay is fed compared to alfalfa silage. Improved farm equipment may make hay harvesting a more practical alternative to silage harvesting in the future.

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