AN ABSTRACT OF THE THESIS OF

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Title: Early-Vegetative Meadow Hay Versus Alfalfa Hay as a Supplement for Beef Cattle Consuming Low-Quality Forages.

Two beef cattle studies and a hay meadow survey were conducted to evaluate high-quality meadow hay as a supplement for low-quality roughages. In the hay meadow survey, forage clippings were taken from one 6.1 hectare pasture once weekly for 7 weeks. The forage clippings were analyzed for changes in production, CP, ADIN, ADF, NDF and IVDMD over time. In Exp. 1, 15 Hereford x Angus ruminally cannulated steers (avg wt = 390 kg) were blocked by weight and randomly assigned to one of three treatments: 1) tall fescue straw, no supplement; 2) tall fescue straw plus meadow hay supplement; 3) tall fescue straw plus alfalfa hay supplement. This 28 d digestion study involved a 14 d adaption period, 6 d of intake, 6 d of fecal collections, a one day rumen profile, and rumen evacuations on the last day. In Exp. 2, 90 gestating Hereford x Angus cows were stratified by age and body condition, and, within stratum, randomly assigned to three replications of the same treatments as above. All cows were kept together in the same pasture, and the supplemented cows were gathered, sorted, and fed their supplements at 1100 h each day. In both studies, a basal diet of tall fescue straw was fed ad-libitum, the alfalfa hay was fed at .4% BW, and the meadow hay was fed at a level isonitrogenous with the alfalfa hay. In Exp. 1, DMI was at least 13% greater ($P<.01$) for supplemented steers than for nonsupplemented steers, and was 12% greater ($P<.1$) for meadow hay versus alfalfa hay supplemented steers. In contrast, straw DMI tended to be depressed for steers receiving supplement compared to nonsupplemented steers ($P=.15$). Dry matter digestibility was greater for supplemented steers than for nonsupplemented steers ($P<.05$), and, within supplement treatments, greater for meadow hay supplemented steers than for alfalfa hay supplemented steers ($P<.10$; 44, 52 and 47% for nonsupplemented, meadow hay and alfalfa hay treatments, respectively). Digestible

DMI was at least 22% greater (P<.001) for supplemented steers than for nonsupplemented steers, and 24% greater for meadow hay supplemented steers compared to alfalfa hay supplemented steers (P<.01). No improvement in the in situ digestion of the basal diet was observed on either supplement treatment. Extent of protein digestion of the alfalfa hay supplement was 7.2% greater than for the meadow hay supplement (P<.05), although the rate of protein digestion of the meadow hay was more than 1.8 X faster than the alfalfa hay (P<.1). No differences in IADF passage rates or outflow were noted, but supplemented steers showed a greater fill than those on the control treatment. Provision of additional protein did not appear to affect either ruminal pH or VFA concentration (which were inversely related). Volatile fatty acid concentrations were highest in meadow hay supplemented steers, and lowest in alfalfa hay supplemented steers. Acetate to propionate ratios increased with supplementation (P<.0001), and were higher in the alfalfa hay supplemented steers than in the meadow hay fed steers (P<.0001). Ruminal ammonia values peaked at 3 h post-feeding, and were higher for supplemented steers than for the control treatment at 0 h through 6 h post-feeding (P<.1). In Exp. 2, supplemented cows gained more weight than nonsupplemented cows (P<.001), and the meadow hay supplemented cows gained more weight (P<.10) than cows supplemented with alfalfa hay (7.5, 31.4 and 23.6 kg for nonsupplemented, meadow hay and alfalfa hay fed cows, respectively). Likewise, cows on supplements lost less condition (P<.01) than their nonsupplemented counterparts during the 84 d supplementation period, and the meadow hay cows tended (P=.23) to lose less condition than the alfalfa hay supplemented cows (-1.43, -.40, and -.72 units for nonsupplemented, meadow hay and alfalfa hay fed cows, respectively). Nonsupplemented cows showed a stronger recovery of lost weight and condition than the supplement treatments after calving when the supplementation had been discontinued. No differences in calving weight was noted between treatments. In conclusion, high-quality meadow hay supplementation of cows on low-quality forage appears to produce performance comparable to, or better than alfalfa hay supplements when fed on an isonitrogenous basis.

(**KEY WORDS:** Beef Cattle, Supplementation, Meadow Hay, Alfalfa Hay)

Early-Vegetative Meadow Hay Versus Alfalfa Hay as a Supplement for Beef Cattle Consuming Low-Quality Forages

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INTRODUCTION

Commercial beef production systems in the Western United States which depend upon range forages have to contend with great changes in forage quality across seasons. In many cases, cows must rely on poor quality forages during critical production periods, gestation in particular. Winter range forages, especially grasses, are poor in quality primarily because they have entered dormancy and have been exposed to the elements which have bleached and leached many nutrients out of their tissues. During dormancy, perennial plants shift most of their soluble carbohydrates towards the base and roots for storage until spring regrowth begins. What tissue is available for grazing generally is only modestly digestible and low in protein. Producers may be forced to supplement the forage, replace it, wholly or in part, with hay, or be forced to liquidate stock when feed conditions are especially poor. Acceptable conception rates and calf performance require that cows reach parturition in good physical condition. Since the viability of a cow-calf operation hinges upon beef cow reproductive performance, it is imperative that cow nutrition during gestation and lactation be at least adequate. What producers look for, then, are means of economically meeting the nutritional requirements of their cows over periods of poor forage quality.

Many regions have access to cheap forage resources which may be underutilized. Cereal grain straws, various forage residues and stovers, and stockpiled range forage all have potential to provide the substance of a basal diet for cattle, although most of these sources are generally too low in protein and too high in indigestible fiber to support even ruminants without supplementation. Use of these forage sources in conjunction with proper supplementation, however, does hold promise for providing producers with an economical, nutritionally acceptable winter diet.

In regions where warm-season grasses predominate, this forage-based supplementation strategy may also be effective. Warm-season grasses are generally much less digestible than their cool-season counterparts, like those which are abundant

in the Pacific Northwest. Their modified physiologies and warmer growing environment conspire to magnify the density and lignification of their structural tissues. If, as some suspect (Owens, et al., 1991), additional protein, particularly in the rumen fiber mat itself, increases plant fiber fermentation, then forage-based protein supplements may be useful in optimizing production on these forages.

While concentrate supplements have long been popular, research has indicated that forage-based supplements are also effective - and in many areas forage supplements may be somewhat less expensive than concentrates. This is particularly true when ranches have the resources to produce their own hay. In regions where ranches maintain hay meadows for the production of winter feed, the capacity to switch from producing large quantities of low-quality forage to producing somewhat less, but higher quality forage may enable producers to manage their resources more flexibly and economically from year to year. High-quality hay used as a supplement for low-quality winter, stockpiled, or residue forages may be a better option for ranchers in some years than winter-long haying. Furthermore, by not having to maximize hay production for winter feeding, producers may open up new possibilities for managing hay meadows, such as early season grazing, which may improve their ability to efficiently manage their total resource base.

This research project, the discussion of which begins on page 33, was designed to describe both the technical effects and practical utility of such a combined meadow and cattle management program. The hay meadows were grazed early in the season, then harvested at the normal time - although the early grazing retarded forage growth such that at harvest time it was less mature, therefore of higher quality than it otherwise would have been. Low-quality grass straw was utilized as the base diet. Compared to grass hays and alfalfa, these straws are relatively cheap. Alfalfa generally can be found for $85-100/ton, and grass hay often sells for $55-65/ton. Grass straw residue can be purchased for $25-30/ton, however. Even if both the forage supplement and the straw basal diet were purchased, the cost of the total diet would still be less than full-feeding with either hay, since even a forage-based supplement should not make up more than 30% of the total diet. Further, by

incorporating early-season meadow grazing into the management plan, producers may be able to reduce some of their late-winter/early-spring feeding.

Effects of two forage-based supplements, alfalfa hay and meadow hay, were compared with each other and both against a nonsupplemented group in both the digestion trial and the winter cow performance trial. The studies complemented each other in that while the performance study gave an indication of the practical utility of such a dietary strategy, the digestion trial offered an opportunity to understand the driving forces behind the differences in performance which were observed.

While it is true that other supplementation and forage modification strategies have been shown to be successful, such as the use of protein concentrate or NPN supplements, pelleting, and ammoniation of forages, this strategy is one which enables producers to utilize on-ranch resources intensively and flexibly. Even when purchased low-quality forage residues are used, the producer is dealing with a commodity for which there is little competition, and, at the present time, few forces driving price fluxuations. It is to be hoped that the results of this research will allow producers to develop new managerial strategies which will enable them to produce with increasing economy.

REVIEW OF THE LITERATURE

RUMINANT EVOLUTION

Sometime during the early Eocene (roughly 40-55 million years ago) the predecessors of the herbivorous mammalian vertebrates we now refer to collectively as artiodactyls first emerged. The artiodactyls evidently radiated into a number of different forms very rapidly. In fact, by the end of the Eocene all major groups of artiodactyls had emerged. The four artiodactyl families recognized as true ruminants (the Pecora), the Antilocapridae, the Cervidae, the Giraffidae, and the Bovidae, began appearing in the early Miocene, about 25 million years ago (Carroll, 1988). Because modern grasses also began proliferating in the early Miocene, the explosion of ruminant species from the early Miocene into the Pleistocene has been largely attributed to the emergence of the grassland ecotype. While it may be true that some ancestors of modern percorans first began developing specialized digestive processes in order to detoxify secondary plant compounds, a tactic which further generalized their diets (Hume and Warner, 1980), it appears that the relatively greater availability of grass cellulose under the ruminant pregastric microbial fermentation process provided these animals with an exploitable advantage over other grazers. Presumably this advantage partly explains why percorans replaced a large number of perissodactylid species, the percorans' only major competitors in their particular niche, as the late Oligocene gave way to the Miocene. Approximately 170 species of percorans, among the four families, are still alive today, while only a handful of species of the once varied and numerous perissodactyla remain extant.

RUMINANT DIGESTIVE STRATEGY

The digestive system of true ruminants is similar to that of simple-stomached mammals from the gastric stomach on down. What is different about the pecorans are the specialized pouches which have developed just anterior to the stomach

(abomasum). Percorans have three distinct pregastric pouches (all modern artiodactyls except the suids [pigs] have pregastric modifications of some kind, but none so elaborate as in the pecorans), the reticulum, the rumen, and the omasum. These pouches, the rumen in particular, serve to hold ingesta in an environment favorable to microbial degradation through chiefly anaerobic fermentation processes. The rumen is the largest of these organs in adult animals, often occupying the full posterior half of the left abdominal cavity. In true bovids, which have adapted to the most fibrous forages of all ruminants, the omasum is the second largest of the three pregastric pouches, but in ruminants which have adopted a more selective grazing system the omasum is typically the smallest (Church, 1988). More than merely a passive organ in which to ferment roughages, the rumenoreticular complex also mixes the digesta through muscular action, and forms ingesta boluses which are regurgitated, remasticated, and reswallowed, a process known as "rumination". The rumen, which is lined with villi and papillae, is also an important site of nutrient and water absorption.

The increased digesta retention time made possible by the voluminous rumen and exposure of the digesta to cellulase-producing microbes permits ruminants to remove more nutrients from highly fibrous forages than other vertebrates. This ability makes ruminants particularly well-suited for existence in environments where fiberous forages are the principal feedstuffs. The ruminant strategy has its limitations, however. At sizes in excess of 1,000 kg, rumination which is essential for the fermentation process becomes impractical. The volume of digesta simply cannot be processed by the comparatively small mouth quickly enough. Furthermore, the digestive tracts of very large animals are extensive enough to ensure adequate retention times to allow extraction of the more digestible forage components. A large animal's nutritional requirements can generally be met without the need for rumination so long as a high intake can be maintained (Van Soest, 1982).

The effectiveness of rumen microbial activity means that very little intact digestible carbohydrate reaches the lower gut in ruminants on forage diets. Consequently, ruminants have had to develop a means of generating glucose from

other compounds - principally volatile fatty acids (VFA), which are synthesized by rumen microbes. While the VFA propionate is the principal glucose precursor in ruminants, glucose carbon can also be derived from lactate, isobutyrate, isovalerate, valerate, glycerol from by-passed lipid or from certain amino acids. Propionate is metabolized to glucose in the liver through the tricarboxylic acid (TCA) pathway. Other odd-carbon VFA enter the same pathway, but are split into propionate and acetate as they are metabolized (Van Soest, 1982).

ROLE OF RUMINANTS IN MODERN AGRICULTURE

Continued rapid expansion of the world's human population has placed great demands upon agriculture. Although it is more economical to feed people cereal grains directly than through the intermediation of livestock, over 65% of the world's land area is unsuitable for cultivation (Van Soest, 1982). Much of that land area does produce forages which can be utilized, however, and the low-quality straw and stover byproducts of cereal grain production are also suitable under certain conditions, with supplementation, as ruminant feeds. Moore et al. (1967), in fact, estimated that three times the domestic ruminant population of the 1960's in the U.S. could be supported by such straw and stovers alone were all tillable land in the country put into cereal crops - an unlikely prospect, but it illustrates a role ruminants have the potential to play in the larger agricultural "picture".

Animal products remain the best sources for high-quality protein in human diets, and the ability of ruminants to convert low-quality plant protein into high-quality meat and milk protein is an important feature in both developed and so-called "underdeveloped" societies. This study is intended to further explore a means by which ruminants may be used this way in an economical fashion, through the use of a low-quality straw supplemented with a high-quality forage-based protein source.

FORAGE CHARACTERISTICS

Forage quality is an important factor in ruminant digestive performance. Forage quality has several dimensions. There is the nutritional aspect, which is concerned with nutrient composition and quantity found in plant tissues. Forage digestibility, another aspect, which along with passage rate has important effects on intake, is affected by forage structural and chemical characteristics which can vary widely according to species, maturity, and environmental conditions. One of the principal determinants of forage fiber digestibility is the extent of lignification. A currently popular theory suggests that lignin and structural carbohydrates can form complexes through ester, ether, and(or) hydrogen bonds which cannot be readily cleaved by fermentative action. Lignin has proved to be highly soluble in alkali, although such treatment has been associated with depression in digestion rates and increases in rates of passage (Van Soest, 1982). Proportions of cellular contents relative to cell wall materials and nutrient composition of plant tissues, particularly protein content, also affect digestibility.

Generally speaking, forages progressively decline in quality with advancing maturity. As the reproductive stage is neared, structural materials like cellulose and lignin build up at a more rapid rate than soluble carbohydrates, like fructosan. Nitrogen compounds make up increasingly smaller fractions of the total dry matter with maturity, and there can be net losses of protein after full maturity is reached because of leaf losses and increases in the stem to leaf ratio. Dry matter digestibilities (DMD) tend to decline as this maturation advances (Blaser, 1964).

PROTEIN

Protein plays important roles not only in tissue formation and deposition in the host animal, but it also is crucial for microbial fermentation. Properly balanced rations therefore must not only meet the needs of the animal in question, but also the needs of the rumen microflora (Van Soest, 1982). Protein content in forages, however, varies

considerably with species, maturity, and environment - but it is the effect of maturity which is of principal interest in this research project.

Pendlum et al. (1980) found that Kenhy fescue was highest in crude protein (CP) in the early vegetative stage, lowest in the dough stage, and intermediate during vegetative regrowth after clipping (17.58%, 7.74%, and 11.11%, respectively). Spahr et al. (1961) observed that orchardgrass declined in CP from 12.4% on May 25 to 9.6% on June 9. Correlating quality to plant phenology, Lloyd et al. (1961) found that CP levels in timothy declined with advancing maturity. Crude protein levels at early bloom were 10%, at half bloom they were 8.1%, at full bloom they were 6.3%, and post bloom levels dropped to 5.9%. Buxton and Marten (1989) compared the changes in CP of four different grass species and found that they all showed a marked decline from May 10 to July 5. Tall fescue declined from 30.7% to 7.9% in this study. According to Blaser (1964), these changes occur because structural tissues are laid down more rapidly as the plant matures towards its reproductive phase. The plant protein, which is found mainly in the leaves, comprises increasingly smaller fractions of the plant total dry matter (DM) as stem growth increases relative to leaf growth, and as leaves are lost from the plant.

FIBER

Plant fiber is largely composed of polysaccharides which are chemically linked together in such a fashion that mammalian digestive enzymes cannot cleave them. Although cellulose and hemicellulose, the principal carbohydrates classified as fibrous, are composed of sugars, the fermentation process degrades them into VFA, not simple sugars. While VFA are not generally principal energy sources for nonruminants (they use glucose liberated from carbohydrate digestion directly), ruminants are able to convert them, primarily propionate, into glucose for use by somatic tissues (Van Soest, 1982). Although nonruminants experience some residual VFA production through fermentative processes in the cecum and colon, absorption from the lower tract is poor. This fact prevents VFA from being an important energy source for nonruminants. In

ruminants, on the other hand, very little digestible carbohydrate escapes ruminal fermentation intact, consequently glucose cannot be liberated directly but must instead be formed from VFA metabolism.

The relative proportion of plant cell wall to cellular contents, and the degree of lignification are the principal determinants of forage nutritive value. Cellular contents, which include most of the plant protein, starch, sugars, lipids, organic acids and soluble ash, are nearly totally digestible (Van Soest, 1982). As the plant matures the cell walls thicken and are lignified. Lignin is a complex chemical substance which is highly indigestible and tends to bind with structural carbohydrates, reducing their digestibility.

In the study by Pendlum et al. (1980), lignin (% of dry matter) increased from 2.7% at the early vegetative stage to 5.6% at the dough stage of Kenhy fescue. Lloyd et al. (1961) observed that lignin increased with advancing phenological stages of timothy. At early bloom it comprised 5.3% of forage dry matter, at half bloom 7.4%, at full bloom 9.7%, and by post bloom it had grown to 10.1% of the total. Crude fiber also increased, 27.8%, 30.3%, 31.5% and 33.2% at early, half, full and post-bloom, respectively. From May 25 to June 9, Spahr et al. (1961) observed the crude fiber in orchardgrass to increase from 31.4% to 35.2% of dry matter.

FORAGE DIGESTIBILITY

Varying nutritional content and structural components have direct effects upon digestion, indeed, lignin content is closely related to cell wall digestibility across forage species (Van Soest, 1982). Raleigh et al (1964) found that digestibility values for nitrogen, dry matter, cellulose and gross energy all declined significantly for meadow hay harvested at advancing stages of maturity. Lloyd et al. (1961) observed a similar decline in digestibilities for timothy harvested across advancing maturity. Dry matter digestibility declined from 65% to 48%, and crude fiber digestibility declined from 65% to 46% from early bloom to post bloom. In tall fescue, Bagley et al. (1983) showed declines in dry matter and cell wall digestibility from May to July of 67.5% to

57.4% and 67.9% to 57.1%, respectively. Rai et al. (1971) reported a decline in tall fescue digestibility from 66.2% to 45.8%.

While the preceding studies utilized in vivo measurements, in vitro estimations of relative forage digestibilities have also been made. Pritchard et al. (1963) compared in vitro digestibilities of six grasses, and described significant digestibility declines in all of them from early vegetative stages through the post-flower stage. Tall fescue in vitro dry matter digestibility (IVDMD) decreased from 65.3% to 42.6%. Rai et al. (1971) showed a decline in tall fescue IVDMD from 62.5% to 45.5%. These estimations are of digestion extent, not rate, and generally are most highly correlated to in vivo digestion at about 36 h (VanSoest, 1982; Church, 1988). In vitro values also may give some indication of intake. The maximum correlation between in vitro digestibility and intake occurs between 6 and 12 h, which corresponds most closely to cell soluble digestion (Van Soest, 1982). This suggests that the ratio of cell contents to cell wall, particularly with low-quality forages may give some indication of the portion of intake most strongly related to digestibility.

Crop residues, stockpiled forages, and mature grass hays generally will have low cell content:cell wall ratios, low CP values and relatively high degrees of lignification. These factors all conspire to impair the digestibility of these feeds to ruminants. There is a challenge, then, to find economical ways of improving the utilization of these forages. While intake and digestibilities have been increased by various chemical and mechanical modifications of forages, protein supplementation has also shown promise as a means to improve low-quality forage use.

EFFECTS OF PROTEIN SUPPLEMENTATION OF LOW-QUALITY FORAGES ON RUMINANT DIGESTIVE PERFORMANCE

MECHANISMS OF ACTION

McCollum and Horn (1989) described five possible mechanisms of action by which protein supplementation may affect ruminant digestion and(or) performance: (1) it may supply protein to correct N deficiencies of ruminal microorganisms, (2) may increase flow of intact protein to the lower gut, (3) may correct tissue-level amino acid imbalances (quality), (4) may increase the supply of amino acids to the tissues (quantity), and (5) may increase the supply of amino acids for glucogenesis, and recycled N which may improve intake and ME utilization.

FORAGE INTAKE

Diets lower than 6-8% in CP are known to be associated with depressed forage intakes. Such intake limitations are suspected to be due to either or both a host tissue-level nutrient deficiency, and (or) a N deficiency in the rumen microbial environment (Van Soest, 1982). The rate at which protein is degraded in the rumen relative to the rate of carbohydrate digestion is also thought to be critical. Some have suggested that carbohydrate digestion is improved when nitrogen is liberated at a rate synchronous with the carbohydrate (Doyle, 1987). Research by Conrad et al. (1963) suggests that in diets with DMD values less than 66%, intake is closely correlated with the amount of indigestible material in the digestive system, and its passage rate out of the tract. There may be a degree to which this phenomenon is itself some function of ruminal nitrogen availability, since nitrogen often is a limiting agent in microbial degredation of dietary fiber.

Regardless of the mechanism, there are a number of studies which have documented improvements in forage intake with various protein supplements. Caton et al. (1988) found that forage intake was higher in steers supplemented with

cottonseed meal/corn grain than those fed a control diet (8.1% CP). On a prairie hay diet which tested 5.2% CP, Guthrie and Wagner (1988) observed a similar increase in forage intake with soybean meal supplementation. DelCurto et al. (1990c) found that steers supplemented with protein (soybean meal/sorghum grain, long-stem alfalfa hay, or dehy alfalfa pellets) had forage intakes which were at least twice as great as steers fed the control diet alone which had tested 2.7% CP. Supplementation does not affect forage intake in all cases, however. Judkins et al. (1987) observed no differences in forage intakes between fistulated steers fed a basal diet (ave 8.5% CP) without supplementation, and two isonitrogenous supplements: pelleted alfalfa (ave 17.5% CP) and cottonseed cake (ave 43.6% CP). There were significant differences in total intakes, however. The alfalfa supplemented steers had the highest intakes, followed by the cottonseed cake supplemented animals.

Upon the basis of studies, like that of Blaxter and Wilson (1963), a range between 6 and 8% CP in the forage diet has become established as the level below which protein supplementation has greatest effect on intake and performance (McCollum and Horn, 1989). Milford and Minson (1964) observed that intake of tropical forages likewise declines sharply as forage CP falls below 7%.

RUMEN KINETICS

The limitations of reticulo-rumen capacity (fill), and its relief through indigestible digesta passage and post-fermentation absorption are considered to be the primary factors influencing intake on coarse forages (Egan, 1970; Van Soest, 1982; Church, 1988). Most intake changes are seen as functions of adjustments in one or more of these factors, although there is growing evidence for some form of post-ruminal metabolic control as well (Egan, 1965).

RUMINO-RETICULAR FILL. Van Soest (1982) attributes changes in reticulo-rumen "fill" (weight/volume of digesta) to rumen stretch factors: that the rumen can expand and contract somewhat to accommodate varying amounts of digesta. He

suggests that an animal's tolerance for degrees of such expansion depends upon its appetite, which changes according to how near circulating levels of certain nutrients (probably caloric) are to meeting nutritional requirements. Such a mechanism would led one to expect that fill must increase as nutrient density of the diet declines. This theory has been supported by some studies, including Wheeler et al. (1979), but not all.

Campling et al. (1961) and Montgomery and Baumgardt (1965) found that fills for some diets of low digestibility were lower than for diets of higher digestibilities (reported by Egan, 1970). Egan (1970) observed that fills were greater in sheep fed alfalfa hay than those fed oat or wheat straw. Mature ewes on a prairie hay diet (6.3% CP) were found to increase their reticulo-rumen fills upon supplementation with cottonseed meal in a study by Krysl et al. (1987). However, Judkins et al. (1987) found no differences in fill between steers grazing native forage alone (8.4% CP) or supplemented with alfalfa pellets or cottonseed cake.

Further evidence that something other than satiety or maximal distention plays some role in regulating intake has been produced by Egan (1965), and Egan and Doyle (1985). In 1965, Egan observed that duodenal protein infusions increased intake and rumen fills in sheep fed low-quality forages (<3.5% CP), though neither passage rate or digestibility were affected. Evidently, the increased intakes were strictly a function of the greater rumen fills stimulated by the protein. Egan and Doyle (1985) likewise were able to induce increased fills in sheep fed a forage containing 5.2% CP by infusing urea into their rumens. While the mechanisms behind this phenomenon have not been adequately described yet, it seems likely that host tissue nitrogen status is an important factor - particularly on low-quality forage diets, where ruminal microbes may utilize most of the nitrogen which is liberated before it escapes to the lower tract.

RATE OF PASSAGE. Passage of indigestible particulate matter is one of two means by which the reticulo-rumen is emptied of digesta. On forage diets which have an abundance of cell wall, indigestible particulate passage is an important determinant of intake, since lower diet digestibilities leave more digesta to be emptied through tract

passage. Higher passage rates have often been associated with greater intakes resulting from protein supplementation. Guthrie and Wagner (1988) and Stokes et al. (1988) separately reported linear increases in rates of particulate passage with increasing levels of soybean meal. McCollum and Galyean (1985) likewise observed increased particulate passage rates when low-quality prairie hay (6.1% CP) was supplemented with cottonseed meal, as did Caton et al. (1988) when supplementing steers on dormant native forages (7% CP) with cottonseed meal. These three studies also reported increases in forage intake with supplementation. DelCurto et al. (1990a) described a quadratic response in ruminal indigestible acid detergent fiber (IADF) passage to graded levels of protein supplementation.

However, Fleck et al. (1988) observed no changes in particulate passage rates as a result of supplementation on a basal forage diet of 5% CP. The intake increases were instead attributed to a greater total diet digestibility resulting from the supplementation. Judkins et al. (1987) saw only a tendency towards greater passage rates in steers fed alfalfa pellets against steers fed cottonseed cake or no supplement on a forage diet which averaged 8.43% CP. Otherwise passage rates between treatments were equivalent. Krysl et al. (1987) also found no passage rate differences between steers on a treatment fed a 6.3% CP prairie hay, and a treatment supplemented with cottonseed meal. DelCurto et al. (1990b,c) saw no differences in IADF passage in two studies comparing various protein supplementation regimens to nonsupplemented controls on a basal diet of 3% CP.

DIGESTIBILITY

There are several components involved when diet digestibility in ruminants is being considered. First, there is the total tract digestibility, which may be described either in terms of *apparent* digestibility or *true* digestibility of a diet. Apparent digestibility reflects the simple difference between total intake and total fecal output, digestibility being the relative proportion of intake which is not recovered in the feces. True digestibility adjusts the apparent digestibility formula to account for the fact that

a portion of the fecal output arises not from undigested feed but from microbial and endogenous epithelial tissue sources. The proportion of microbial and tissue contributions to the feces vary with the diet and the stage of production. One means of overcoming the difficulties involved in determining true digestibility is to concentrate on ruminal fermentation instead, since the in situ technique permits finding digestion values for individual feed components.

Since lower gut digestion in ruminants varies in few respects from that in other mammals, emphasis in ruminant nutrition is generally placed on reticulo-rumen digestion. Rumen digestion (fermentation) is generally described both in terms of rate (proportional disappearance/unit time) and extent (proportion of total which disappears within a determined time). Such measurements are typically taken according to the in situ, or "nylon bag", technique, where a measured quantity of forage is suspended within the rumen digesta in a porous bag for a defined period of time, after which disappearances of various feed constituents are determined. Rate is found by suspending a series of such bags for increasing increments of time, and regressing disappearance values across the time scale. Soluble dietary components are the most fully and rapidly fermentable portions, while insoluble forage fractions tend to be less digestible depending largely upon their degree of lignification.

APPARENT DIGESTIBILITY. Digesta kinetics (which involves the various flows of feed components through the rumen), intake, and microbial digestive efficiencies are the main determinants of apparent dry matter digestibility (DMD). Protein supplementation of low-quality forages generally improves DMD. The response of digesta kinetics and microbial digestion of basal forage components to supplementation varies across studies, but total diet intakes and total diet digestion are very often seen to increase. Certainly the greater inherent digestibilities of most supplements relative to the basal forages plays an important role in improving total diet characteristics. Since apparent digestibility provides no means of separating the contribution of different feedstuffs to fecal output, digestibility values can only be found for the total

diet. For this reason the in situ technique was developed, because digestibilities can be assessed for discrete dietary components.

Stokes et al. (1988) reported a linear increase in apparent digestibility for beef cows fed prairie hay supplemented with soybean meal at two levels. Guthrie and Wagner (1988) described the same phenomenon in a study involving steers fed a basal forage diet (5% CP). The nonsupplemented treatment showed an apparent DMD value of 49.6%, where the low-level supplement group had a value of 54.3% and the high-level supplementation group had a combined apparent digestibility value of 58.4%. Wheeler et al. (1979) reported greater digestibility for high-quality orchardgrass (10.1% CP) than for barley straw or corn stover (4.2%, 4.1% CP, respectively). Among the four combinations of low/high protein X low/high energy, DelCurto et al. (1990a) observed the lowest DMD value (39.1%) in the low protein/low energy treatment, and the highest DMD value (47.5%) in the high protein/high energy treatment. This provides some evidence, then, that protein supplementation may improve total diet digestibility. However, these improvements do not appear in all situations, and the factors which determine the degree of effect are not clearly understood (DelCurto et al., 1990b). How much the additional free protein a supplement provides improves digestibility needs to separated somewhat from the effects of additional carbohydrate which may also be included in the supplement in order to more clearly define the mechanisms at work here.

RUMINO-RETICULAR IN SITU DIGESTION KINETICS. Generally speaking, the speed of fermentation is a function of nutrient quality, quantity, and solubility, as well as the population size and activity of resident cellulolytic microbes. Soluble materials, such as sugars and starches, disappear very rapidly, leaving the relatively less soluble fiberous material to determine the latter end of the digestion curve (Van Soest, 1982). It is most accurate, then, to describe separate rates of fermentation for different dietary components. Less soluble structural materials may be digested at a more rapid rate after the addition of nitrogen to N-deficient diets. Presumably this is

due to improved metabolic activity of the cellulolytic bacteria which are responsible for degrading plant fiber.

Wheeler et al. (1979) found a greater digestion rate for orchardgrass hay (5.24%/h) than for barley straw (4.49%/h) or corn stover (2.73%/h). While in situ neutral detergent fiber (NDF) disappearance was greater at 4, 8, 12 ,18, and 36 h in steers receiving cottonseed meal compared to steers given no supplement on a 7% CP forage diet, Caton et al. (1988) reported no significant differences in overall digestion rate (3.0%/h vs 3.4%/h).

As with rate, a greater extent of rumen fermentation is also thought to result from improved ruminal N status. The extent to which digesta is fermented, however, is a function both of rate and retention time in the rumen. Presumably, highly fiberous material has a longer retention time in the rumen simply as a result of the extra time it takes for it to be physically reduced in size enough to pass out of the fiber mat and through the omasal orifice. While the digestion rate for highly soluble material may be much greater than for insoluble cell wall components, soluble materials are absorbed or washed out of the rumen at a much higher rate also. Caton et al. (1988) reported a 3% increase in the extent to which organic matter in the forage basal diet (7% CP) was digested after 48 h in steers supplemented with cottonseed meal (49.6% vs 46.7%). Wheeler et al. (1979) also observed a greater extent of dry matter digestion in orchardgrass (68.5%) than in barley straw (53.8%) or corn stover (42.9%).

RUMEN FERMENTATION DYNAMICS

RUMINAL PH. Rumen pH is closely linked to microbial activity and VFA absorption. The VFA generated as end-products of microbial metabolism tend to shift the pH downwards as they accumulate, though this has a natural corrective in an otherwise balanced system. The pKs for most VFA are near 4.1, therefore the lowering of pH increases the proportion of VFA in the nondissociated (absorbable) form. As the VFA are then removed from the rumen environment at a more rapid rate, the rumen pH increases again. Rumen pH also affects interspecies competition

between microbes, as they differ in their metabolic abilities across the pH scale. Bacteria and protozoa most adapted to starch digestion appear to perform better at low pH (5-6), while cellulolytic bacteria tend to be more competitive at a somewhat higher pH (6-7) (Church, 1988).

McCollum and Galyean (1985) reported no differences in rumen pH according to treatment at various sampling times, and readings ranged from 6.2 to 6.5. Caton et al. (1988) likewise reported no treatment-dependant variation in pH. Measurements averaged 6.4 in both supplemented steers and control steers. Krysl et al. (1987) found no differences in ruminal pH between ewes supplemented with cottonseed meal and those fed prairie hay only (average pH 6.1 and 6.2 for supplement and control treatments, respectively). DelCurto et al. (1990b) found no supplementation effect on ruminal pH. Average pH across treatments was 6.6.

Stokes et al. (1988), however, reported that mean rumen pH decreased linearly with increasing levels of soybean meal supplementation. Mean ruminal pH values reported for control, low supplement, and high supplement treatments were 6.51, 6.42, and 6.41, respectively. DelCurto et al. (1990a) reported a treatment X time interaction for ruminal pH. Ruminal pH was lowest for supplemented steers at 3, 9, and 12 h after supplementation. Another study comparing soybean meal, alfalfa hay and alfalfa pellets reported that supplementation tended (P=.12) to lower ruminal pH (DelCurto et al., 1990c).

AMMONIA LEVELS. Ammonia nitrogen (NH_3-N) is used primarily for amino acid synthesis by bacteria or, when absorbed across the rumen wall, is converted to urea by the liver of which most is excreted through the kidneys in urine or recycled back to the rumen (Van Soest, 1982). While most bacteria species found in the rumen can utilize NH_3-N as the sole source of nitrogen, research indicates that many bacteria will use intact proteins and amino acids preferentially to ammonia (Church, 1988). Ammonia found in the rumen environment is derived from three main sources: the degradation of dietary protein and nonprotein nitrogen (NPN), hydrolysis of urea recycled to the rumen (or provided in the diet), and degradation of microbial cellular

proteins. Ammonia exits the rumen environment through bacterial uptake, absorption across the rumen wall, and washout through the omasal orifice to the lower tract. Absorption of ammonia across the rumen wall increases with concentration, and microbial uptake can be expected to increase as the protein:energy ratio declines. Changes in ruminal ammonia concentration are generally attributed to the dynamic competition which occurs between modes of protein degradation and removal (Church, 1988). However, ammonia concentrations are not uniform throughout the rumen. Concentrations in the floating fiber mat are often reported to be lower than those in the free liquid fraction. Also, in animals fed separate meals ruminal ammonia concentrations will shift across time following each meal. Post-feeding ruminal ammonia concentrations tend to peak earlier for dietary urea than for plant proteins (1 to 2 h vs 3 to 5 h post feeding). When low-quality forages are fed, it is common to observe no peak in ruminal concentrations. Although ammonia requirements are difficult to pinpoint exactly (they can vary greatly for different microbial species, forage particle types, and digestive organs), research conducted so far indicates that ruminal concentrations below 5 mg/dl may impair performance (Owens, et al., 1991). A cautionary note has been made by McCollum and Horn (1989) about interpretations of ruminal ammonia status. Low ruminal NH_3-N concentrations may not only indicate conditions of low production and low utilization, but also high production and high utilization. Bacterial utilization of free ammonia levels present in the rumen environment can vary greatly, depending upon N availability, substrates, and microbial populations.

Aside from simple concentration, it appears that location and timing of ammonia release are important factors modifying the effective use of ammonia. Ammonia is critical for the metabolic activities of cellulolytic bacteria which populate the floating fiber mat in the rumen. However, as noted above, much of the free ammonia is found in the liquid fraction, not the fiber mat. For this reason there may be advantages to feeding proteinaceous forages rather than concentrates as supplements. Supplemental forages will join the fiber of the basal forage in the fiber mat, bringing their additional

nitrogen with them - thereby providing a ready supply for the local microbes (Owens et al., 1991).

Some have suggested that a controlled release of ammonia, at a rate similar to that of the dietary carbohydrate, may improve its utilization. However, no studies have demonstrated this to explicitly be the case, and studies infusing cows with NPN once per week saw no important differences compared against cows infused daily. Nitrogen recycling in ruminants is highly effective, and efficient - particularly when animals are experiencing a negative nitrogen balance. Ruminal ammonia concentrations may be sufficiently high under conditions of adequate nutrition that heavy NPN supplementation and(or) synchronous release of NPN products simply are not necessary.

DelCurto et al. (1990a) reported that ruminal ammonia N concentrations were greatly enhanced by protein supplementation on a low-quality forage diet, and the addition of supplemental energy depressed ruminal ammonia levels. In another study, highest ammonia levels occurred in high protein supplemented steers at 3 h post-feeding (19 mg/dl HP, 6 mg/dl control) (DelCurto et al., 1990b). Rumen ammonias increased linearly with the level of protein supplementation on a low-quality forage (prairie hay) in a study by Guthrie and Wagner (1988). Values reported increased from .71 mg/dl for the control treatment to 2.01 mg/dl for the high protein treatment. Despite a treatment X time interaction, Caton et al. (1988) reported that supplementation increased ruminal ammonia levels. Stokes et al. (1988) found a linear increase in ammonia levels with higher levels of protein supplementation. Average ruminal NH_3-N concentrations were .88mg/dl, 3.20mg/dl, and 4.72mg/dl for control, low, and high supplementation respectively. Peak concentrations were observed at 3 and 12 h post-feeding, while the lowest levels came at 6 h. Krysl et al. (1987) reported a tendency (P=.2) for protein supplemented ewes to have greater ruminal ammonia concentrations than nonsupplemented ewes (3.8mg/dl vs 2.9mg/dl). Peak concentrations in both groups occurred at 1 h post-feeding, and remained stable afterwards. Judkins et al. (1987) failed to find any differences with protein supplementation, however. Rumen ammonia concentrations were generally all below

5mg/100ml. Likewise Wheeler et al. (1979) observed that ruminal ammonia concentrations with orchardgrass hay (10.1% CP; 19.6 mg/dl) were not statistically different from those produced by barley straw (4.2% CP; 15.7 mg/dl) or corn stover (4.1% CP; 24.1 mg/dl).

VFA PRODUCTION. There are three VFA which make up the greater proportion of total VFA production: acetate, propionate, and butyrate. Acetate is produced in the greatest amounts by far, as much as 70% of the total in forage diets (Church, 1988). Most VFA are end-products of ruminal microbial fermentation, though body tissues can metabolize acetate from protein, and some other substances, as well. After the VFA have been absorbed through the rumen wall into the portal blood circulation, most of the escaping propionate and butyrate are removed at the liver, leaving the actetate for tissue use in energy production or lipogenesis. Butyrate is partly metabolized to acetoacetate and (D-)β-hydroxybutyrate (ketone bodies),and used for energy production. Propionate is used principally for glucogenesis. The odd-carbon branched-chain VFA, isobutyrate, isovalerate, and valerate, can be used for glucogenesis also, but they constitute only a fraction of the total VFA production.

The ruminal ratio of acetate production to propionate production has become a popular tool for comparing diets. Forage diets are known both to produce a high proportion of acetate relative to propionate, and to be rather more energetically inefficient that diets higher in propionate. The greater loss of carbon through methane production which is associated with acetate production is one likely avenue of inefficiency, although it is not likely to be the only, or principal, one. However, any assumption that acetate and propionate have relatively constant inherent efficiencies across diets and production situations may need to be reconsidered. Studies have indicated that these efficiencies tend to be variable, changing with dietary conditions and relative proportions of glycogenic and lipogenic metabolites (Church, 1988; Van Soest, 1982). Acetate:propionate ratios alone, then, may not always be adequate indices of dietary quality.

Judkins et al. (1987) observed a proportional shift towards propionate relative to acetate in steers fed a forage diet of 8.4% CP supplemented with alfalfa pellets and

cottonseed cake compared to nonsupplemented steers (A:P= 71.3:20.5 mol/100mol, 73.5:17.3mol/100mol, 75.9:15.4 mol/100mol, respectively). No change in butyrate proportions or total VFA production was noted. Stokes et al. (1988) reported a linear increase in total VFA concentration in beef cows fed prairie hay (4.8% CP) with increasing levels of soybean meal supplement (79.3 mM, 89.0 mM, and 98.3 mM for control, low supp, and high supp, respectively). Linear increases in molar proportions of propionate and butyrate, and decreases in acetate, were also associated with increasing levels of supplement. Isobutyrate and isovalerate both appeared to increase in a quadratic fashion with levels of supplement. McCollum and Galyean (1985) reported lower molar proportions of acetate and increased molar proportions of propionate and butyrate with cottonseed meal supplementation of steers feeding on prairie hay (6.1% CP). Total VFA concentrations were not altered by supplementation, however. In a trial which compared four high-low energy/protein supplement combinations, DelCurto et al. (1990a) also reported no change in total VFA concentration, but acetate concentrations declined relative to propionate as the level of protein increased. An increase in the relative proportion of branched-chain VFA was observed as well. In another study, DelCurto et al. (1990b) found a tendency towards a linear increase in total VFA production with increasing supplemental protein levels. Butyrate and acetate concentrations were unaffected by supplemental protein levels, but propionate concentrations increased with supplement. In a third study reported by DelCurto et al. (1990c) both total VFA and butyrate concentrations in steers fed dormant forage (2.67% CP) were substantially improved with protein supplementation. Ruminal acetate:propionate ratios were 15% lower in alfalfa-based supplement treatments than in soybean meal/grain sorghum or control treatments. Proportions of branched-chain VFA, isobutyrate, isovalerate, and valerate, tended to vary both according to treatment and time.

Krysl et al (1987) saw a tendency (P=.13) towards greater total VFA production in ewes supplemented with cottonseed meal compared to those without supplementation on prairie hay (6% CP). Total VFA levels were reported to be 80.4 mM for the control treatment and 88.6 mM for the cottonseed meal supplemented treatment. No differences in molar proportions of individual VFA were found. Total rumen VFA tended to be greater (109.6 mM vs 95.2 mM, and

100.4 mM vs 89.5 mM) at 1 and 8 h in steers grazing native pastures which were fed a cottonseed meal supplement in a study by Caton et al. (1988). While there were apparently no differences in acetate or propionate concentrations between treatments, ruminal butyrate concentration was increased by supplementation. Wheeler et al. (1979) found no differences in total VFA production or acetate:propionate ratios between orchardgrass hay, barley straw and corn stover.

These studies all serve to underscore the fact that specific fermentation responses to protein supplementation can vary greatly - and the particular conditions responsible for these variations are not all understood. One fairly consistent characteristic, however, is an increase in total VFA production with protein supplementation. This increase in total VFA alone may very well improve a ruminant's energy status sufficiently to express itself through greater production. The meaning of acetate:propionate ratios, and butyrate and branched-chain VFA concentrations, all which showed a great deal of variation in these studies, will hopefully become clearer as more focused research takes place.

EFFECTS OF PROTEIN SUPPLEMENTATION OF LOW-QUALITY FORAGES ON BEEF COW PERFORMANCE

The aforementioned effects of protein supplementation on intakes, ruminal digestive kinetics and fermentation on low-quality forage diets give reason to suppose that performance differences should be observed as well. Indeed, there is a great deal of research which show performance improvements with supplementation under certain conditions.

Because the low-quality forages with which protein supplementation has the most effect are not generally suitable for growing animals, and because such poor quality is characteristic of many winter forages, gestating ruminants, particularly beef cattle, tend to be the subjects of choice in these studies. Weight and body condition gains and losses are the most often studied performance characteristics, although some researchers have also investigated supplementation effects on subsequent reproductive performance and calf growth. It needs to be remembered that the developing fetus

will be adding weight to a cow even as she is losing her own body tissues due to a negative nutritional balance. What may appear to be slight losses over the winter if the calf is not accounted for will prove to be much larger after parturition. For this reason it is common to include some means of evaluating body condition, ie. the degree of subcutaneous fat cover, in order to get a better idea of the cow's actual physiological status. One phenomenon which can be seen in the following studies is that of post-calving compensatory gain. Cows which lost more weight over the winter tend to regain that weight more rapidly after calving than cows that lost less weight. Generally speaking, despite great differences in weight loss over the previous winter, cows will all have returned to a similar weight by the fall provided they are provided adequate amounts of good quality feed. While this may appear to mean that supplementation is therefore not especially crucial except in particularly poor conditions, evidence gathered elsewhere suggests that cows which have lost a great deal of condition over the winter may suffer some degree of reproductive impairment as a result. For this reason a number of studies have attempted to assess the likelihood and seriousness of this problem.

Judkins et al. (1987) observed that cottonseed cake and alfalfa improved gains (control -0.3 kg/d; alf .23 kg/d; csc .24 kg/d) on heifers grazing native pasture when supplemented on an isonitrogenous basis. Working with cows grazing dormant tallgrass prairie, DelCurto et al. (1990b) found that cow weight change over the winter was closely associated with the level of protein supplement being fed; weight changes improved with increasing protein levels (0-120 d wt changes: -87.6 kg, low prot; -55.4 kg, mod prot; -44.0 kg high prot). When the supplementation regimen was discontinued after calving, the nonsupplemented cows showed greater weight recovery than the supplemented cows. By the end of the study, d 275, cow weights across treatments were all statistically similar. Condition changes followed the same pattern, although only the high-protein cows resisted condition loss just prior to calving (0-120 d CS changes: -1.84, low prot; -1.43, mod prot; -.75, high prot). Although there were suggestions of a trend towards heavier calf birth weights and greater numbers of cows cycling before the breeding season with supplementation, there were no significant

differences in calf or reproductive performance data between the groups. DelCurto et al. (1990c) performed another study which compared the relative effects of three different supplemental protein sources (soybean meal/sorghum grain, alfalfa hay, and dehydrated alfalfa pellets) on beef cows grazing dormant range forage. Supplements were designed so that they all supplied a similar amount of CP and ME. Up until the breeding period began at d 182, cows fed the dehydrated alfalfa pellet supplement showed the least weight loss, and those fed alfalfa hay the most (0-182 d weight change: -49.8 kg, SBM/SG; -60.8 kg, AH; -38.1 kg, DAP). After the supplement treatments were discontinued, between the breeding period and trial termination at d 265, SBM and alfalfa hay supplemented cows displayed similarly improved compensatory gains relative to the dehydrated alfalfa pellet supplement. By d 265 weights across all treatments were all similar. The same pattern was repeated in the condition score data. No significant differences were detected in birth weights, pregnancy rates or calving intervals, although there was a tendency towards lower calf gains for the first 55 d in the alfalfa supplement treatment. This seems to provide evidence that the source of supplemental nutrients can have an effect on beef cattle performance. Cochran et al. (1986) studied the effects of alfalfa cubes and cottonseed cake supplementation (both fed to similar protein and energy levels) on performance of wintering cows. Both supplements improved gains and condition scores of treated cows similarly, but the alfalfa cubes were deemed the more economical of the two. DelCurto et al. (1991) studied the relation of protein level to wintering cow performance on dormant forages (<7% CP). While body weight and condition score changes improved with supplemental protein level, the greatest magnitude of change occurred with the low protein supplement. Clanton and Zimmerman (1965) reported higher forage intakes in beef cows grazing grass hay (4.4%-5.8% CP) when they were supplemented with soybean meal. While supplemented cows suffered less weight loss over the winter, control cows always compensated for their losses in the summer months. Unlike some other studies, birth and weaning weights for calves from supplemented cows were consistently greater than for those from the control group. One year of this study, when the forage CP was 8.4% CP, control cows were found to

have higher forage intakes than those which were supplemented. No performance differences were noted that year between treatments.

SUMMARY

As we can see, humankind has, in ruminant animals, a marvelous means of utilizing certain otherwise unavailable natural and agricultural resources for the production of food and fiber not possible through any other current technology. The challenge which continues to face producers, is to find new ways to optimally and efficiently use their ruminant livestock to "transform" available raw materials. There is much left to learn about the mechanics of the ruminant digestive system. It is the ambition of the ruminant scientist to add to this growing body of knowledge so that the world community can benefit by improving its husbandry and use of what we are keenly coming to realize are scarce and diminishing resources on planet earth. Hopefully the research project presented on the following pages will add in some small, but useful manner, to that pool of knowledge.

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EARLY-VEGETATIVE MEADOW HAY VERSUS ALFALFA HAY AS A SUPPLEMENT FOR BEEF CATTLE CONSUMING LOW-QUALITY ROUGHAGES.

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Introduction

The feeding of low-quality forages, such as crop residues, stockpiled forages, and low-quality hays, to wintering beef cattle is a common practice throughout the Western U.S. Without additional nutritional management these feeds frequently result in low intakes and poor digestion owing to deficiencies of host animal and microbially-available protein and energy. Many studies have documented the benefits of protein supplementation on the intake and digestibility of low-quality forages. Caton et al. (1988) reported that in situ NDF disappearance was increased by protein supplementation at 4, 8, 12, 18, and 36 h. McCollum and Galyean (1985), and DelCurto et al. (1990a; 1990c) have reported increases in forage dry matter digestion as a result of protein supplementation. Not only has supplementation been shown to have an effect on digestion and intake, but studies have shown that it can improve performance as well in some cases. Clanton and Zimmerman (1965) observed that protein supplementation improved intake of low-quality forages fed to gestating cows. Also in that study, and in others (Cochran et al., 1986; Judkins et al., 1987), supplemented cows gained more weight than did nonsupplemented cows.

Oilseed meals and alfalfa, the most common forms of supplemental protein in these studies, are relatively expensive in many parts of the Western states. Cheaper, locally produced forms of supplemental protein would be an advantage to many range cattle operations. Meadow hay is commonly produced for use as a primary winter

feed source. Because it is needed in large quantities for this purpose, production strategies frequently emphasize yield over quality, and most hays are therefore harvested close to phenological maturity. Studies by Pendlum et al. (1980), Probasco et al. (1980), and Buxton and Marten (1989) have described the decline in grass forage quality (principally %CP and digestible structural components) which occurs with advancing maturity. It seems reasonable to suppose that meadow hay harvested at an earlier phenological stage might be improved enough in quality to serve as an acceptable, possibly inexpensive protein supplement. In addition, when alternative winter feeds are available, the production of meadow hay as a supplemental forage permits hay meadows to be managed more flexibly than they are in traditional systems. The objective of this study, then, was to harvest such an early, high-quality meadow hay and compare its effects to alfalfa hay on the intake, digestion, and subsequent performance of beef cattle fed a low-quality roughage.

Materials and Methods

Hay meadow survey. Two 6.1 Ha tall fescue pastures were grazed by 108 cow/calf pairs from April 19 to May 17 1991. Cows received 7.7 kg meadow hay/hd on 18 of 28 days. Both pastures had been fertilized with 36.7 kg urea/Ha in mid-March. The early-season grazing was used as a management tool to delay forage maturity so that a higher quality stand could be captured at the normal harvest date. Five clipping plots were established in representative areas within one pasture. Ground-level clippings were taken once every week from five random locations within each plot. The clippings were then weighed, dried, re-weighed, and then ground to pass a 1 mm screen. Total above-ground DM production was estimated from average DM yields across plots. Samples were then stored for later analysis of CP, soluble nitrogen (N), ADIN, ADF, NDF, and IVDMD. Chemical composition of this forage, the alfalfa hay supplement, and the tall fescue basal diet can be found in Table 1. Both pastures were harvested between July 10 and July 15, then the bales were transported to the Eastern Oregon Agricultural Experiment Station for use in the digestion and performance trials.

Cattle trials. Endophyte-free tall fescue straw (grass seed harvest residue of the Bonanza variety) was utilized as the low-quality basal diet for both trials. This straw was fed ad-libitum. The alfalfa hay supplement was fed at .4% BW, a value suggested by previous low-quality forage supplementation trials in this area (DelCurto et al. 1991). The meadow hay was fed at a level which supplied the same amount of protein as the alfalfa hay supplement in order to equalize protein effects on digestion. Both supplement hays and the straw were chopped prior to feeding in the digestion trial. This facilitated handling, weighing, and a reduction in waste resulting from feed pulled out of the bunks. In the cow performance study, the supplement hays and the straw were fed directly from standard rectangular bales.

Exp. 1: Digestion study. Fifteen ruminally cannulated steers (average wt = 390 kg) were blocked by weight and randomly assigned to one of three treatments: 1) tall fescue straw without supplement (negative control); 2) tall fescue straw plus a meadow hay supplement; 3) tall fescue straw plus an alfalfa hay supplement. The 28 d digestion study was divided into a 14 d adaption period, a 6 d intake period, and a 6 d fecal collection period, with a rumen profile on d 27 and rumen evacuations on d 28.

Feed offered and feed refusals were measured throughout the study, and feed and ort samples were collected on d 15 through 26. On d 21 through 26 feed subsamples and 10% of each day's orts were reserved for compositing and analysis. Orts were weighed, dried, reweighed, composited by steer for the fecal collection period, ground, and analyzed for DM, NDF and indigestible ADF. Feeds were handled similarly, composited by type for the fecal collection period, ground, and analyzed for DM, CP, NDF, ADF, ADIN, and indigestible ADF. On d 20 steers were fitted with fecal harnesses and bags. Bags were emptied and weighed once per day, and 2.5% subsamples were taken from each collection, weighed, dried, reweighed for DM,and composited by steer. On d 23 at 2000 h (96 h) a nylon bag (20.0 X 10.0 cm, pore size 53 $\pm$ 10 μm) containing a 4 g sample of 2 mm ground tall fescue straw (basal diet) was deposited in the rumen, suspended within a weighted garment bag. Subsequent bags were introduced into the rumen at 72, 48, 36, 24, 12, and 6 h. In situ

rates of digestion and digestion lag times were calculated as described by Merton and Loften (1980). On d 26 at 2000 h (24 h) a nylon bag (10.0 X 5.0 cm, pore size 53±10 μm) containing a 1 g sample of 2 mm ground alfalfa hay or meadow hay was placed in the rumen of supplemented steers, according to treatment, suspended within a weighted garment bag as above. Subsequent bags were introduced at 18, 12, 9, 6, and 3 h. All bags were removed at 0 h and immediately rinsed, then frozen, awaiting analysis. Ruminal fluid samples were taken at 0, 3, 6, 9, and 12 h after feeding on d 27 for pH, VFA, and ammonia analysis. On d 28 reticulo-ruminal contents were evacuated and weighed immediately prior to feeding (0800 h), and again at 5 h post-feeding. Triplicate subsamples of mixed rumen contents were taken, weighed, dried, reweighed, composited by steer and time, and analyzed for indigestible ADF (IADF).

Exp. 2: Cow performance trial. Ninety gestating Hereford X Angus cows (ave. wt = 479 kg) were stratified by age and body condition and, within this stratum, randomly assigned among three replications of the dietary treatments. All cows shared one common pasture, with the supplemented cows gathered and sorted at 1100 h each day to be fed their supplements. Supplemented cows were fed in pens of 10 according to supplement type. Straw was fed from bales scattered across the pasture each day between 0700 and 0900 h. Supplements were fed for 84 days, from November 19, 1991, to February 11, 1992. Cows were weighed and condition scored (C-scored) on d 0, 28, 56, 84. At 1600 h the day before each weigh/score date, the cows were gathered and placed in a corral away from feed and water overnight. Cow body condition was judged independantly by two observers using a 9-point scale (1 = extremely emaciated, 9 = extremely obese; Neumann and Lusby, 1986). Calf weights were estimated according to a formula based upon heart-girth measurements. Cows were weighed and C-scored again on d 204 (June 11) to find any post-calving differences in weight and condition as a result of winter feeding.

Analytical techniques. Dry Matter and Kjeldahl N were analyzed according to AOAC (1984). Acid detergent fiber and NDF analyses were performed according to Goering

and Van Soest (1970). Determination of IADF was accomplished by a 144-h in vitro fermentation followed by ADF extraction as described by Cochran et al. (1986b) run on triplicate samples. The technique described by Tilley and Terry (1963) was used to determine IVDMD. Mertens and Loften's (1980) log transformation methodology was used to calculate in situ rate of DM and protein disappearance and lag time. In situ nylon bags were rinsed, frozen, thawed and dried in a 100° C oven, and analyzed for DM or protein. Actual procedures for DM and protein in situ were based upon Ørskov (1982). The technique described by Van Soest (1982) was used to determine IADF passage by dividing the IADF intake by the quantity of IADF in the rumen. Determination of pH was according to AOAC (1984), using a combination electrode. Following treatment with .1 N HCL (4 ml acid to 4 ml rumen fluid) and 25% metaphosphoric acid (1 ml acid to 4 ml rumen fluid), samples used for VFA and ammonia analysis were frozen at -20° C. Volatile fatty acid concentrations were determined utilizing a fused silica capillary column[1] in a gas chromatograph[2]. Rumen ammonia concentrations were determined using a hypochlorite method, as described by Broderick and Kang (1980), and a narrow-band spectrophotometer[3] at 630 nm. Soluble N was determined by soaking 1 g samples in 50 ml of distilled H_2O at room temperature for 2 h, stirring occasionally. Samples were filtered, again with distilled H_2O, then the sample residue was analyzed for N according to AOAC (1984). Insoluble N (residue N) was subtracted from original sample N to find sample soluble N. All samples were ground in a Wiley mill to pass a 1 mm screen, except for the in situ samples which were ground to 2 mm.

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[1]Alltech Associates, Inc., Deerfield, IL

[2]5890 Series II gas chromatograph; Hewlitt Packard Co., Analytical group, San Fernando, CA.

[3]Model UV 160, Shimadzu Corp., Kyoto, Japan.

Statistical analysis. All data related to intake, digestibility, in situ digestion, liquid kinetics and IADF flow in Exp. 1 were analyzed as a randomized complete block design with effects for treatment and weight block. Since they were all fed individually, the steer was considered the experimental unit. Digesta kinetics and ruminal profile data based upon the two evacuation times were analyzed as a randomized complete block, split-plot design. When treatment X time interactions were observed ($P<.1$), treatments were analyzed within time periods.

In Exp. 2, the 90 cows were each assigned to three replications of the three dietary treatments, yielding nine groups of 10 cows apiece. Cow weights and body condition scores were analyzed according to a completely randomized design, with "group" as the experimental unit.

General linear measures procedures of SAS were used to analyze all data in these studies (SAS, 1988). Differences among treatments were evaluated using preplanned contrasts of 1) the influence of supplementation and 2) alfalfa hay versus meadow hay.

Results and Discussion

Hay meadow survey. Average CP levels across plots ranged from a high of 24% to a low of 9% (Table 2). The decline in CP is probably due to a progressive accumulation of structural components (reflected in ADF and NDF values), and leaf losses (Blaser, 1964). The percent soluble N values (Table 2) declined by approximately 7% from May 23 through July4, although these results were quite variable across dates. While the primary forage species in these pastures was tall fescue (*Festuca arundinacea*) a number of other grasses were also present, principally orchardgrass (*Dactylis glomerata*), cheatgrass (*Bromus tectorum*), and Kentucky bluegrass (*Poa pratensis*). Two plots included regions with a substantial cheatgrass component, and as this grass matures much earlier than the other species, quality decline was not completely uniform across plots. It needs to be noted that the production estimations were made upon the basis of ground level clippings, and do not represent harvestable forage. Likewise, quality determinations on the clipped forage

included the lower, leaf-poor and more lignified portions of the grass plants which would be left behind by harvesting equipment. Therefore the quality estimations of the clipped forage may be somewhat poorer than what the actual harvested forage would have achieved. As Pendlum et al. (1980) found with Kenhy tall fescue, CP declined with maturity and NDF and ADF fractions increased with maturity. The IVDMD results obtained from this survey were similar to, albeit higher, than those reported by Pritchard et al. (1963).

Exp. 1: Steer digestion study. *Intake and digestibility.* Total DMI ranged from 13 to 26% greater (P<.01) for the supplemented treatments than for the negative control group (Table 3). Likewise, total DMI was 12% greater (P<.10) for the meadow hay supplemented treatment than it was for the alfalfa hay supplemented treatment. In contrast, straw DMI showed a slight depression (up to 9%) for the supplemented treatments compared to the negative control group (P=.15). Dry matter digestibility was 8 to 19% greater for supplemented treatments than for the control (P<.05), and, within supplement treatments, was greater for meadow hay supplemented steers than for alfalfa hay supplemented steers (P<.10). Digestible DMI was more than 22% greater (P<.001) for steers on the supplement treatments than for animals on the control diet, and 24% greater for steers on the meadow hay supplement treatment than for steers supplemented with alfalfa hay (P<.01). We observed a slightly greater extent (2%) of basal diet in situ DM disappearance in the steers on the alfalfa hay supplement relative to the meadow hay fed steers (P<.05). This difference, however, does not appear large enough to have biological significance. Otherwise, there were no differences (P>.10) in in situ DM digestion between treatments. These results seem to indicate that the additional protein provided by the supplements did not aid digestion of the basal diet. The increases in basal diet NDF digestibility reported by Caton et al. (1988) are not reflected here. The improvement in total diet digestion without improvement of basal diet digestion indicates that digestive performance was largely a function of each supplement's own relative digestibility. Lower ADF and IADF values for meadow hay versus alfalfa hay (Table 2) suggest that the fibrous

component of the meadow hay may have been more readily digestible than that of the alfalfa hay. The importance of this becomes more apparent when it is remembered that the meadow hay was being fed at a level 1.6 times higher than the alfalfa hay, a fact which may have further magnified the available energy in the diet of the meadow hay supplemented steers. Observations returned from the protein in situ work showed alfalfa hay to have a greater extent of ruminal digestion, P<..05, than the meadow hay in this case (Table 4). Lag time was about an hour less, on average, (P<.05) and rate of digestion was 1.8 X faster (P<.1) for the meadow hay compared to alfalfa.

Digesta kinetics. While there were no notable differences between treatments at the 0 h evacuation, both DM fill and IADF fill differed between supplemented and nonsupplemented treatments at the 5 h post-feeding evacuation (P<.01 and P<.05, respectively), with supplementation resulting in greater fill (Table 5). There were no other significant kinetic differences resulting from supplementation, although there were evidences of three trends: (1) liquid volume tended to be greater (P=.12) in the supplemented steers than in the control steers 5 h post-feeding; (2) IADF passage tended to be faster (P=.1) in the control treatment relative to the supplement treatments; and (3) the alfalfa hay supplemented steers appeared to show a somewhat greater (P=.12) IADF outflow compared to the meadow hay supplemented steers.

Rumen fermentation characteristics. Protein supplementation, per se, evidently did not affect rumen pH (Table 6) because the control treatment gave a value which fell between those of the supplement treatments. There was a significant difference in pH between supplement treatments, however, which raises the possibility of some other supplement-related effect. Indeed, pH values correspond to total VFA (TVFA) values - alfalfa hay having the lowest concentrations and meadow hay the highest. Other supplementation studies have reported either no effects on pH or a decrease in pH (Krysl et al. 1987; Stokes et al. 1988; DeCurto et al. 1990b). As with pH, the control treatment showed a TVFA concentration (Table 6) which was intermediate to the supplement treatments. It is unclear why the alfalfa supplement group had the lowest TVFA concentrations. Previous research has shown a lack of effect or a positive effect on TVFA with supplementation (McCollum and Galyean, 1985;

DelCurto et al., 1990a; DelCurto et al., 1990c). Total VFA concentrations were much higher in this study than those reported by other researchers (Caton et al., 1988; Stokes et al., 1988). Since these studies utilized warm-season grasses, it may be that perhaps the differences in TVFA levels are reflecting a digestibility difference between warm and cool-season species. Acetate to propionate ratios were seen to increase with supplementation, a result which is at odds with the reports of many studies (Judkins et al., 1977; Stokes et al., 1988). The alfalfa hay supplemented treatment had the highest average ratio, followed by the meadow hay treatment. These results are difficult to interpret in the absence of other studies reporting similar results. Caton et al., 1988 and DelCurto et al., 1990c both reported increases in butyrate with protein supplementation. Results from this study do not indicate a supplementation response, although the meadow hay treatment showed a 30% increase over the alfalfa hay treatment concentration ($P<.1$), and a 19% increase in concentration over the control group. Isobutyrate, isovalerate, and valerate, gave treatment X time interactions ($P<.1$). These results are shown graphically in figures 2 through 4. In all cases the alfalfa hay treatment had the highest relative concentrations, followed by the meadow hay treatment. The control group always had the lowest relative concentrations. Isobutyrate and isovalerate were peaked at 0 h, then declined towards 12 h post-feeding. Valerate showed peak proportions at 3 h post-feeding, then declined - most rapidly from 6 to 12 h. Control responses were markedly weaker for all three of these VFA than for the supplement treatments. Ruminal ammonia concentrations showed a treatment X time interaction (Figure 1). At 0 h all three treatments were statistically distinct ($P<.1$), with the meadow hay treatment having the highest average concentrations, and the control group the lowest. Concentrations peaked at 3 h post-feeding, with significantly greater ammonia levels ($P<.1$) in the supplemented treatments than in the control group. At 6 h post-feeding the supplement groups were still showing higher concentrations ($P<.1$), though by 9 and 12 h post-feeding ammonia concentrations in all treatments had declined to similar levels. Ammonia concentrations in this study were similar to those reported elsewhere (DelCurto et al., 1990b; Guthrie and Wagner, 1988; Stokes et al., 1988).

Exp. 2: Cow performance trial. The results of this study described pronounced effects, both of supplementation and type of supplement on cow weight gains and body condition changes over the winter. Supplemented cows in this study gained more weight (>16 kg; P<.001) than nonsupplemented cows over the 84 d supplement feeding period, and the meadow hay supplemented cows gained more weight (>7 kg; P<.10) than the alfalfa hay treatment. Cochran et al. (1986), Judkins et al. (1987), and DelCurto et al. (1991) have all reported similar weight change advantages with supplementation. In the same way, cows on supplements lost 50% less body condition than their control counterparts (P<.01), and the meadow hay cows tended to lose less condition (about 44%) than the alfalfa hay fed cows (P=.23). This also agrees with several previous studies (Cochran et al., 1986; Delcurto et al., 1991). After calving, the nonsupplemented cows showed an improved recovery of weight and condition compared to the supplemented cows. Bearing in mind that the 84 d weights included near-term fetuses which were similar in weight across treatments, the 204 d weight changes reflect a compensatory gain in the control cows at least fourfold greater than the recovery seen in the supplemented cows. This agrees with observations of similar compensatory gains seen in nutritionally constrained animals on other supplementation studies (Clanton and Zimmerman, 1965; DelCurto et al., 1990 b,c). The recovery of body condition followed the same pattern. Recovery of condition was inversely related to the degree of condition lost over the winter: control cows regained condition the fastest, meadow hay supplemented cows the slowest. Unlike Clanton and Zimmerman's study (1965), no differences were observed in calf birth weights as a result of supplementation. Although differences in various measures of reproductive efficiency are expected from animals on dissimilar nutritional planes, impairments or enhancements of performance are not always observed. DelCurto et al. (1990b) reported numerical trends towards greater birth weights and improved conception rates in supplemented cows, but the differences were not especially strong. Since the winter season through which this study was conducted proved unusually mild, it may be that the cows were not sufficiently physiologically taxed to show an effect on fetal development.

The potential production advantage conferred by supplementation, especially through periods of physiological stress, is clear. Without supplementation, cattle on such low-quality diets are unable to meet their nutritional needs and consequently may manifest symptoms of poor nutrition in terms of impaired reproductive performance, such as low conception rates, delayed estrus and puberty, poor milking, and reduced resistance to stress and disease.

Implications

The results obtained by this study suggest that high-quality meadow hay is an effective supplement to low-quality forages, particularly in terms of animal performance. However, the addition of supplemental protein failed to improve basal diet intake or digestion. The treatment differences which were observed appeared to be a function of energy provision rather than protein, although the protein probably was necessary to make the supplemented energy available. Supplementation significantly increased total diet intake, depressing basal forage intake only slightly. While basal diet digestion was not improved by supplementation, total diet dry matter digestibility and NDF digestibility increased significantly with the contribution of supplement. Improvements in gain and body condition seen in the performance study likely were most related to increases in total intakes and improved dietary digestibilities which came with supplementation. Forage-based protein supplementation appears to be a very practical means of improving wintering cow weight and condition maintenance on low-quality forages. While calf birth weights were not seen to improve on this study, the great differences in weight and condition of the cows suggest that it is reasonable to suspect wintering cattle in many areas would require such supplementation in order to maintain acceptable levels of reproductive performance on low-quality diets.

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Table 1. Chemical composition of feeds

	Tall fescue straw	Meadow hay	Alfalfa hay
CP, %	4.05	11.92	18.97
% Sol Prot	37.65	23.87	28.38
ADIN[a], %	12.93	6.76	9.32
ADF, %	50.38	34.95	35.26
NDF, %	73.63	57.01	51.71
IADF[b] , %	32.89	7.75	18.16

[a]Expressed as a percentage of total N
[b]Indigestible ADF

Table 2. The influence of sampling date on production and chemical composition of tall fescue meadow forage

	Sampling						
	5/23	5/30	6/06	6/12	6/20	6/27	7/04
DM prod.kg/Ha	46.66	86.44	146.86	252.77	392.95	494.61	587.85
CP, %	24.43	21.87	18.90	16.06	11.67	10.98	9.42
% Sol Protein[b]	44.07	46.81	37.39	37.62	42.07	39.53	37.23
ADIN[a], %	3.10	3.10	2.79	3.38	5.14	4.51	5.69
ADF, %	24.02	23.93	24.94	26.95	33.59	31.44	34.10
NDF, %	43.94	45.6	42.25	46.14	52.89	51.99	56.93
IVDMD., %	77.43	77.93	80.52	78.55	72.15	73.55	69.80

[a]Expressed as a percentage of total N
[b]Expressed as a percentage of total protein

Table 3. Effects of early-vegetative meadow hay and alfalfa hay supplementation on intake and digestibility of treatment diets

Item	Treatments			SE[a]	Contrasts	
	Control	Meadow hay	Alfalfa hay		Supplement vs non-supplement	Meadow hay vs Alfalfa hay
Intake, kg/day						
Total DMI	6.62	8.36	7.46	.32	.0106	.0794
Straw DMI	6.62	6.05	6.03	.32	.1778	.9517
Supp DMI	-	2.31	1.43	-	-	-
Intake, %BW						
Total DMI	1.71	2.12	1.97	.08	.0099	.2107
Straw DMI	1.71	1.53	1.59	.08	.1511	.6227
Supp DMI	-	.59	.38	-	-	-
DDMI[b] (kg/day)	2.89	4.36	3.53	.14	.0003	.0036
DMD[c], %	44.00	52.2	47.4	1.68	.0225	.0781
NDF dig, %	41.05	49.38	42.71	1.76	.0494	.0281
Basal diet in situ dig. kinetics						
Lag, hrs	3.84	3.84	3.86	.04	.8691	.8519
Rate (% /hr)	1.08	1.08	1.09	.05	.9752	.9141
Extent, %	57.67	57.26	58.57	.35	.5875	.0315

[a]SE = Standard error of the means (n = 5)
[b]Digestible DMI
[c]Apparent DM digestibility

Table 4. Effects of early-vegetative meadow hay and alfalfa hay supplementation on protein digestion

Protein Digestion	Treatments		SE[a]	Contrast
	Meadow Hay	Alfalfa Hay		Meadow Hay vs. Alfalfa Hay
Extent (%)	76.2	83.4	.014	.0219
Lag (h)	1.87	2.92	.27	.0487
Rate (%/h)	13.5	7.2	.02	.0831

[a] SE = Standard Error of the means (n=5)

Table 5. Effects of early-vegetative meadow hay versus alfalfa hay supplementation on digesta kinetics

	Treatments			SE[a]	Contrasts	
	Control	Meadow hay	Alfalfa hay		Supplement vs non-supplement	Meadow hay vs Alfalfa hay
DM fill (kg)						
0 hr	8.29	8.40	8.32	.61	.9255	.9283
5 hr	10.22	11.61	11.95	.35	.0067	.5857
Liquid volume(*l*)						
0 hr	60.47	63.48	60.96	2.91	.6362	.5578
5 hr	73.67	78.85	81.74	3.09	.1176	.5278
IADF[b] fill (kg)						
0 hr	3.75	3.74	3.80	.28	.9497	.8817
5 hr	4.20	4.71	5.06	.21	.0275	.2756
IADF[b] passage/hr (%)						
0 hr	2.36	2.28	2.40	.15	.9241	.5857
5 hr	2.13	1.80	1.79	.15	.1032	.9630
IADF[b] outflow (g/h)	88.3	84.2	90	5.0	.3688	.1196

[b]Indigestable ADF
[c]SE = Standard error of the means (n = 5)

Table 6. Effects of early-vegetative meadow hay and alfalfa hay supplementation on pH and major VFA levels

	Treatments				Contrasts	
	Control	Meadow hay	Alfalfa hay	SE[a]	Supplement vs. non-supplement	Meadow hay vs. Alfalfa hay
pH	6.6	6.4	6.7	.014	.4652	.0001
Total VFA (Mm)	144.6	160.0	127.9	3.97	.8939	.0001
Acet:Prop	3.33	3.42	3.63	.02	.0001	.0001
Acetate (mol/100 mol)	69.5	68.4	70.8	.61	.9030	.0081
Propionate (mol/100 mol)	21.0	20.1	19.6	.20	.0001	.0701
Butyrate (mol/100 mol)	7.91	9.44	7.23	.79	.6636	.0525

[a] SE = Standard error of the means (n=5)

Table 7. Influence of early-vegetative meadow hay versus alfalfa hay supplementation on cow weight and condition score changes, and calf birth weight

	Treatments				Contrasts	
	Control	Meadow hay	Alfalfa hay	SE[a]	Supplement vs non-supplement	Meadow hay vs Alfalfa hay
Initial						
Body weight, kg	478.43	479.20	482.83	-	-	-
Condition score	5.47	5.42	5.33	-	-	-
d 0-28						
Weight change, kg	+12.80	+12.80	+13.98	2.83	.8704	.7781
C-score change	-1.00	-.68	-.73	.12	.0940	.7778
d 0-56						
Weight change, kg	+15.03	+26.18	+23.17	2.63	.0239	.4485
C-score change	-1.08	-.40	-.72	.17	.0137	.3135
d 0-84						
Weight change, kg	+7.54	+31.37	+23.61	2.65	.0009	.0844
C-score change	-1.43	-.40	-.71	.16	.0054	.2311
d 84-204						
Weight change, kg	-3.29	-17.12	-12.75	3.41	.0325	.4097
C-score change	+.67	+.02	+.44	.14	.0377	.0763
d 0-204						
Weight change, kg	+4.68	+15.73	+11.65	4.85	.1749	.5741
C-score change	-.74	-.30	-.31	.11	.0151	.9791
Calf Birth Weight (kg)	36.60	36.65	36.26	.54	.8394	.6400

[a]SE = Standard error of the means (n = 3)

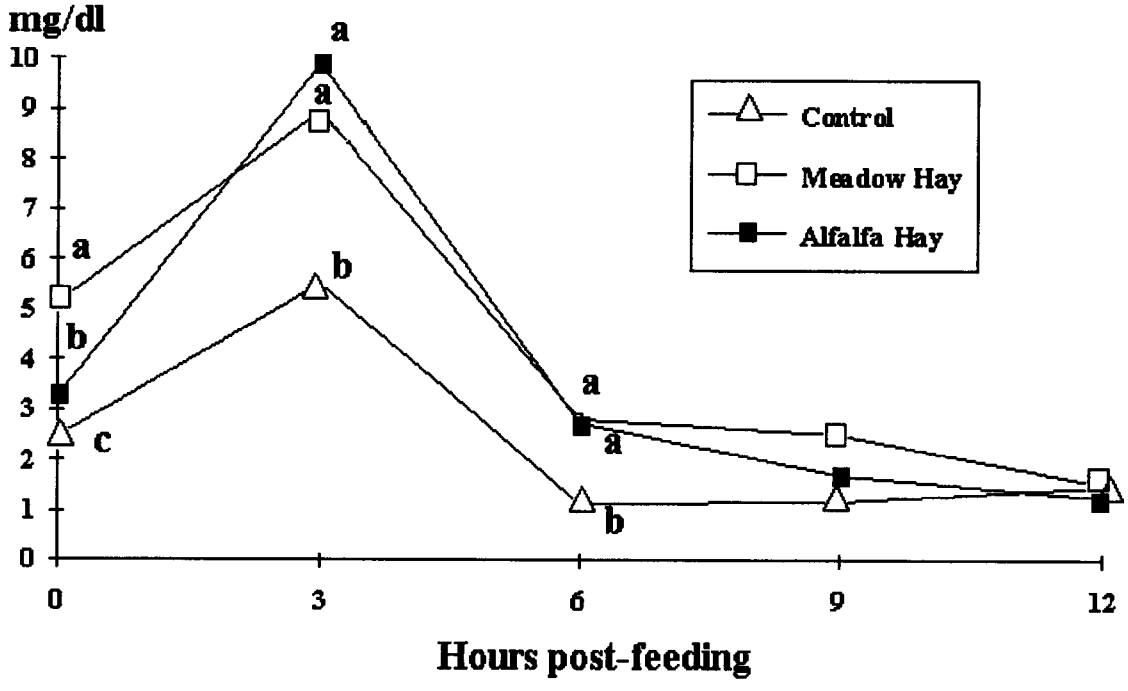

Figure 1. Effect of early-vegetative meadow hay and alfalfa hay supplementation on rumen ammonia concentrations. Differing superscripts[a,b,c] indicate statistical differences of at least P<.1 at individual sampling times.

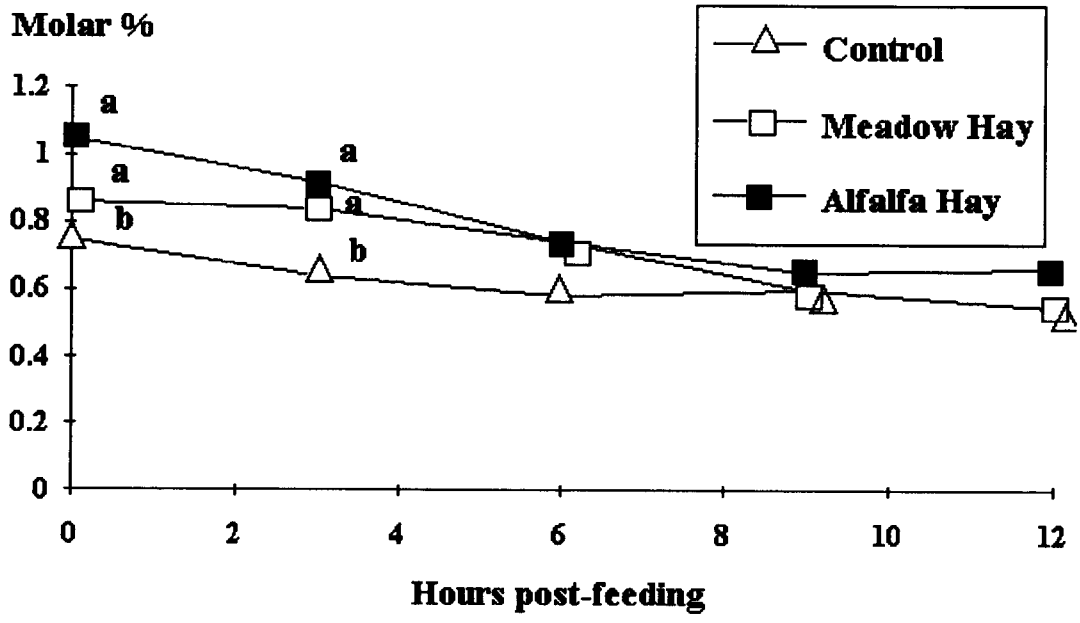

Figure 2. Effect of early-vegetative meadow hay and alfalfa hay supplementation on isobutyrate concentrations. Differing superscripts[a,b] indicate statistical differences of at least $P<.05$ at individual sampling times.

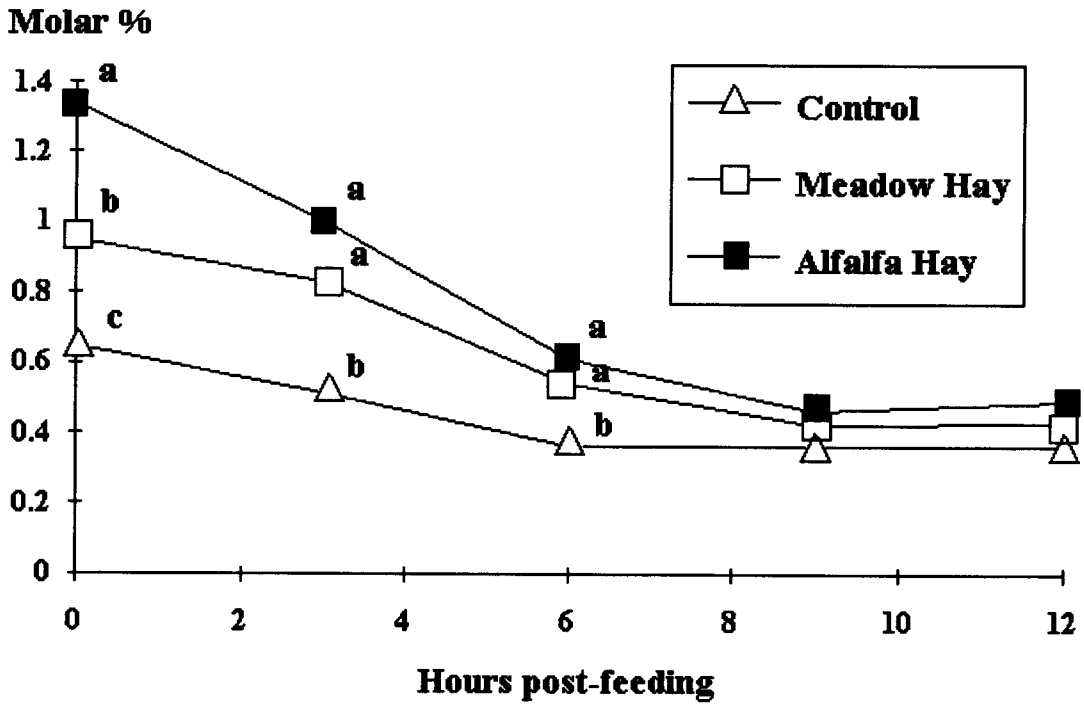

Figure 3. Effect of early-vegetative meadow hay and alfalfa hay supplementation on isovalerate concentrations. Differing superscripts[a,b,c] indicate statistical differences of at least $P<.05$ at individual sampling times.

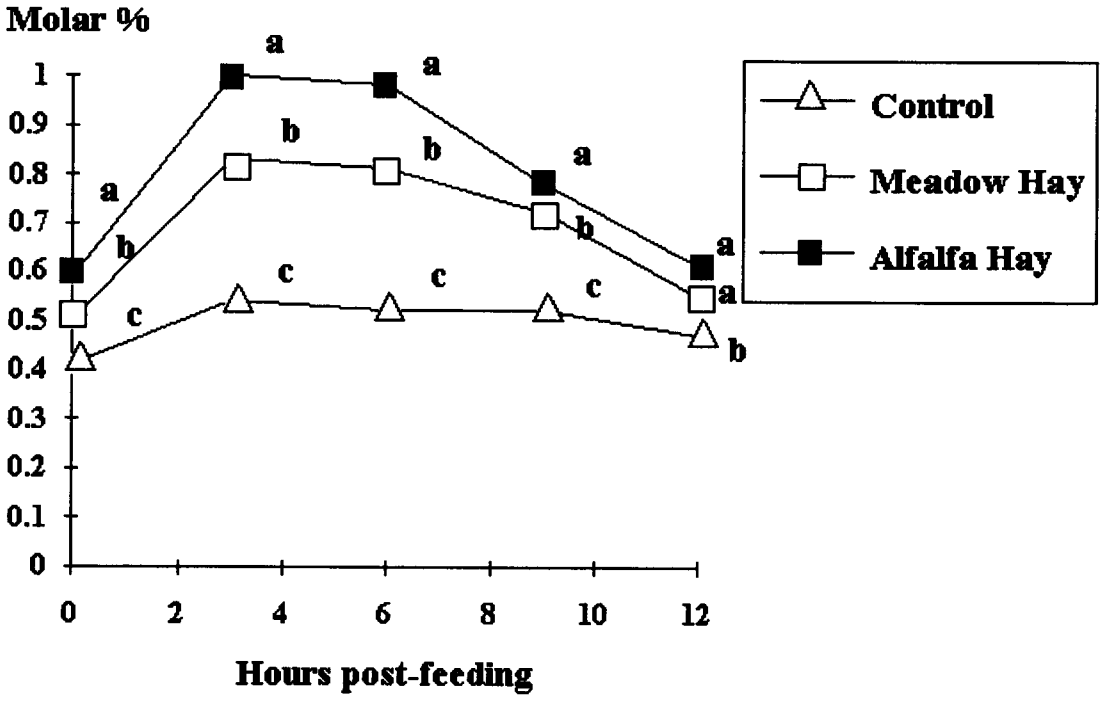

Figure 4. Effect of early-vegetative meadow hay and alfalfa hay supplementation on valerate concentrations. Differing superscripts[a,b,c] indicate statistical differences of at least P<.05 at individual sampling times.