# FEEDS AND FEED ADDITIVES, RUMINANT FEEDS

## 1. Introduction

Many species of ruminants exist worldwide (1). The feeds and feed additives common to U. S. agriculture for the nutrition and management of domesticated ruminant animals, ie, cattle, sheep, and goats are discussed.

Ruminants that consume plant materials grown on land unsuitable for crop farming need not compete with humans and non-ruminant livestock for feed resources. At least one-third of the world's land area is more suitable for grazing than for cultivation (1,2). Typical high-fiber forage produced on such land is practically indigestible by non-ruminants, and thus best utilized by ruminant animals. Ruminant animals, whose ruminal microflora ferment and digest cellulose, the predominant component of fiber, and the most abundantly produced carbohydrate (3), utilize much of the plant energy produced on this land (3). Anatomical differences between monogastric and ruminant animals allow the ruminant to be more efficient in digesting cellulose, but generally less efficient in gaining weight and in converting feed to gain because of energetic losses resulting from the fermentation process, typical of ruminant digestion.

The ruminant has a four-compartment stomach, as opposed to the single-compartment stomach of monogastric animals. The esophagus delivers food after oral ingestion, to the reticulum, the first compartment. The reticulum is attached directly to the rumen, the principal fermentation compartment. The rumino-reticulum compartment makes up at least 60% of the total stomach compartment in cattle and sheep (4). A sphincter muscle between the rumen and omasum (the third stomach compartment) regulates feed outflow from the rumen. The omasum filters contents flowing between the rumen and abomasums and also squeezes much of the fluid contained in the ruminal mass (5). Following the omasum is the abomasum, which is more like the true stomach of monogastric animals. Gastric juices such as hydrochloric acid [7647-01-0], as well as proteolytic enzymes, are the primary secretions of the abomasum (5). The reticulum and rumen serve as a large fermentation sac where anaerobic bacteria, protozoa, and fungi exist. When particle size is reduced sufficiently, the solid material passes from the rumen into the omasum. A portion of solid food is regurgitated (ruminated) between meals so that it may be remasticated, reswallowed, and fermented further.

Compartmentalization of the stomach is the principal trait allowing ruminants to utilize fibrous feeds (5). Certain species of microorganism present in the rumen secrete cellulase [9025-56-3] that degrades cellulose by fermentation, primarily to acetate, propionate, and butyrate. The ruminal microbial population also degrades and resynthesizes nitrogen compounds in the ingested feeds into microbial protein, a relatively high quality amino acid mixture that passes to the small intestine. The lower pH of the abomasum lyses the microorganisms passing through the rumen. The released microbial protein is more nearly like the animal's amino acid requirements than that contained in plant protein sources.

## 2. Feeds

**2.1. Forages/Roughages.** Approximately 75–80% of the feed fed to ruminants during their lifetime production cycle is forage/roughage material (6). Roughages are made up predominantly of the stem or stalk portion of plants and usually include the seeds and leaves of such plants. Such feeds, typically are higher in crude fiber, >50% neutral detergent fiber; low in starch, <4%; and moderately low in crude protein, <20%. Roughages not only are a source of nutrients to the ruminant, but they also help maintain normal rumen function. Generally, roughages are more economical than concentrates, and thus serve in a maintenance (nonproductive) situation. In addition, roughages play a role in additional management practices such as weaning the young ruminants from milk on to solid feed; preventing metabolic diseases, ie, bovine ketosis and ovine pregnancy toxemia; and, maintaining proper fat level (~3.5% in milk produced by Holstein dairy cows). In the young ruminant weaning process, forage in the diet helps establish a normal gastrointestinal tract microbial population.

Ruminants consume forages either by grazing or by being fed harvested material. Grazing reduces input costs to the producer, but it does not allow any control over the amount and quality of forages consumed by the animal. Since one-third of the world's land area is classified as grassland not adapted for cultivation (2), grazing and forage harvesting for ruminant consumption is a must for utilizing such feed potential.

The moisture content at which a plant is harvested usually determines its storage method. Low (15–25%) moisture forages often are stored in some type of baled (and tied) form and no attempt is made to exclude oxygen from it. Various types of oxygen limitation are utilized for storing higher (40–75%) moisture forages, ie, stave silos, oxygen-limiting silos, concrete bunker silos, in-ground pit silos, and large plastic bags (weenie bags) (7). Such higher moisture forages are protected from aerobic access—as nearly as possible—in order to permit the anaerobic bacteria to cause fermentation of the available carbohydrates to lactic acid [598-82-3], acetic acid [64-19-7], propionic acid, [79-09-4], and butyric acid [107-92-6], and to produce an acid environment of a pH between 3.6 and 4.6. Forage stored in this manner will remain at status quo indefinitely, until oxygen is introduced. Common examples of high moisture forages are known as silage and haylage. Silages can be made from harvested and chopped plants, usually corn, sorghum, or small grain, but also may be made from forages. Haylage generally contains less moisture than silages, ie, 40–60% moisture. Alfalfa haylage is the most commonly fed haylage in the United States.

Several different sources of low moisture forages, eg, prairie hay, alfalfa, bromegrass, orchard grass, and blends of hay are grown specifically for the purpose of harvesting. Also, crop residues such as corn stalks, soybean stubble, or small grain straws are available. Because the source of these forages/roughages is highly variable, the quality of such feed also is variable. Alfalfa is an excellent forage source and is harvested in both the high (haylage) and low (hay) moisture forms. It contains a relatively high (20%) amount of crude protein and a moderate (40–50%) amount of neutral detergent fiber. More information on alfalfa is available (8,9).

**2.2. High Energy Feeds.** Concentrated sources of energy are fed to ruminants to allow young animals to grow more rapidly and efficiently. Feedstuffs of this nature generally are high in readily fermentable carbohydrates, ie, they are high starch-containing feedstuffs. Feedstuffs containing high amounts of starch often are from the seeds of plants such as corn, grain sorghum, oats, and barley (9). Wheat also is a highly digestible feedstuff although its demand as a human food makes its use as a feed cost-prohibitive. Millets are of minor importance except in areas of Asia, Africa, and the Commonwealth of Independent States (formerly Soviet Union) where millet can be grown successfully in drought-stricken areas (5). Rye sometimes is fed to ruminants. However, several compounds in rye have been identified (10) that may decrease its usefulness as an energy source. Crossing wheat and rye produces a hybrid grain called triticale (5). Animals consuming triticale have not grown as efficiently as expected, possibly because of the presence of trypsin and chymotrypsin inhibitors (11), alkyl resorcinols (12), water-soluble pentosans (13), and ergot (5), as well as low acceptability by the animal (14) (see WHEAT AND OTHER CEREAL GRAINS).

By-products of agricultural commodities are used as readily-fermentable energy-containing feedstuffs. Molasses, a by-product of the sugar-refining industry, is an excellent source of carbohydrates for ruminant feeding. It contains at least 46% sugar, a trace of protein, and 15–25% water (5). The addition of molasses to rations increases feed acceptability, reduces dustiness of the mixture, and improves feed pelleting. Molasses from citrus and wood processing are also utilized as ruminant feeds (5,9). Other useful energy-containing by-products include wheat bran, wheat middlings and shorts, dried citrus pulp, dried beet pulp, dried bakery waste, hominy, potato meal, whey, corn gluten feed, and rice bran. Since tremendous amounts of agricultural by-products and residues exist (15), a great quantity of ruminant feedstuffs is available, which is not utilizable for human food or monogastric animal feeding. Such by-products often are used as a feed nutrient source for ruminant feeding because of availability and low cost. Some of these may present problems such as being lower in energy content or possibly less acceptable by animals than is true for corn (9).

Feed processing methods influence the availability of energy from feedstuffs, probably by influencing the sites of digestion and absorption in the ruminant animal (Table 1). The data in Table 1 was obtained from 605 comparisons in which finishing cattle were fed high concentrate diets, and the data was

Table 1. **Effect of Processing Method on Energy Content (Mcal/kg dry matter) of Barley, Corn, Milo, Oats, and Wheat for Finishing Beef Cattle**[a]

| Processing method | Barley | Corn | Milo | Oats | Wheat |
|---|---|---|---|---|---|
| dry roll | 3.40 | 3.26[b] | 2.94[b] | 3.36 | 3.32[b] |
| high moisture | | 3.41[b] | 2.98[b] | | |
| steam roll | 3.52 | 3.73[b] | 3.56[b] | 3.31 | 3.64[b] |
| whole | 2.85 | 3.56[b] | | | |
| reconstituted | | | 3.10[b] | | |

[a] See Ref. 16.
[b] Means within a column with different superscripts differ ($P < .05$).

published in North American journals and experiment station bulletins since 1974.

Fermentation products produced in the rumen and absorbed through the ruminal wall do not contain as much energy as carbohydrates absorbed through the small intestine (6). Methods of processing include grinding, rolling, cracking, extruding, steam flaking, roasting, heating, wetting, and gelatinization. More information on feed processing methods is available (5,9).

Various sources of lipids have been incorporated into ruminant rations to increase energy density. This practice is followed in high producing dairy cattle. Addition of fat will reduce the dustiness of rations, increase ease of pelleting, and increase feed acceptability.

The predominant source of lipid utilized in ruminant rations is of animal origin (5). Animal fat, typically, is higher in saturation and often is referred to as grease. Various sources of vegetable lipids are available, and usually are oils, which contain a higher amount of unsaturation than animal fat; such oils can come from corn, cottonseeds, soybeans, olives, safflower seeds, sunflower seeds, rapeseeds, and peanuts (5). Whole cottonseed are being used in increasing amounts for dairy diets as energy enhancers during lactation (17).

Lipids present in the ration may become rancid fairly quickly. When included at levels $>4-6\%$, lipids may decrease acceptability, increase handling problems, result in poorer pelleting quality, cause diarrhea, reduce feed intake, and decrease fiber digestibility in the rumen (5). To alleviate the fiber digestibility problem, calcium soaps or prilled fatty acids have been developed to escape ruminal fermentation. Such fatty acids then are available for absorption from the small intestine (5). Feeding whole oilseeds also has alleviated some of the problems caused by feeding lipids. A detailed discussion of lipid metabolism by ruminants is available (17).

## 3. Supplements

**3.1. Protein.** Although most feedstuffs contain protein, supplemental protein or nitrogen often is required to meet animal physiological requirements. Practical situations in which supplemental protein is required include the feeding of growing/immature animals, lactating females, females in the last trimester of pregnancy, and those grazing nonleguminous forage, such as on range land pasture. The ruminal microflora require not only energy, but also an available source of nitrogen. The nitrogen source does not need to be totally in the form of protein; some of it can be in the form of non-protein nitrogen (NPN), such as biuret, urea, ammonia, or poultry waste. Substitution of too great an amount of NPN for natural protein does not always result in similar performance. A part of this discrepancy could occur because preformed protein usually contains energy and possibly minerals (18). Increased performance from feeding preformed protein may occur because some ruminal bacteria require branched-chain volatile fatty acids (VFA's), derived from branched chain amino acids (19) and that are essential for normal performance (19). Non-protein nitrogen should be limited to no $>50\%$ of the nitrogen included in the diet.

Soybean meal is the protein supplement utilized most frequently in the United States (9). Oilseed meals used in lesser quantities include cottonseed meal (contains gossypol that restricts its use for poultry and swine), canola meal (derived from rapeseed), and linseed meal (derived from flax seed). Additional meals derived from the oil-extraction process include peanut, sunflower, safflower, sesame, coconut, and palm kernel (4).

Raw soybeans may be used as a source of supplemental protein, but because of urease content, it cannot be used in rations containing urea. Also, raw soybeans contain a trypsin-inhibitor that prevents its use in poultry and swine diets. Dry beans, ie, beans normally harvested in the green, immature state, such as fava, lupins, field peas, lentils, and other grain legumes contain sources of supplemental protein.

Various milling, distilling, and brewing by-products are available as supplemental protein sources. Corn gluten meal (60% protein), and corn gluten feed (20–25% protein) are derived from the wet milling of corn, Both products contain varying amounts of xanthophyl, but protein contains a poor balance of amino acids. Wheat middlings (15–20% protein) is the offal from wheat milling. Distilleries produce distillers' dried solubles and grains (26–35% protein), as the by-product of liquor and wine production. Brewers grains (26–29% protein) are a by-product of beer production, and are produced from barley fermentation.

Legume forages, such as alfalfa or clover, are considered high quality, available sources of protein for ruminant animals. Animal proteins were seldom utilized in ruminant diets until the concept of ruminal escape protein was developed by the author of this article—plus co-workers at Purdue University. High producing ruminants such as rapidly growing young animals or lactating dairy cows need amino acids supplied by such ruminal-escape protein, and that may not be synthesized in the ruminal process. The most widely used animal proteins include hydrolyzed poultry feather meal, blood meal, fish meal, and meat-and-bone scraps from non-ruminant animals. Meat-and-bone-scraps from ruminant animals may not be fed to ruminants because of possible transmission of BSE, or "Mad Cow Disease."

Protein nutrition of ruminants involves the rate of ruminal degradability that is indicative of the amount of protein escaping the rumen, unscathed. Ruminal escape (by-pass) protein is a term used to describe the amount of protein that escapes ruminal fermentation and thus is passed to the gastric portion of the gut where it may be digested and absorbed. This aspect was discovered by the author of this article, and is of great interest to those developing ruminant rations. Proteins are analyzed for the amount of ruminal degradation that occurs.

Supplemental energy may be needed when the majority of the animal's diet is from bulky feedstuffs such as poorer quality roughages. In the case of cows grazing rangeland, protein intake may, or may not, be adequate; furthermore, the ruminal microflora may lack a fermentable source of carbohydrates. In such case, a highly fermentable starch source such as corn or sorghum grain may need to be supplied. Such practice may enhance the efficiency of forage utilization for such animals.

**3.2. Minerals.** The most universally deficient mineral element(s) in ruminant diets is salt (sodium chloride) because very little is found in such diets. However, salt is so economical and can be supplied so readily (ad libitum, loose, block or in a mixture) it should not be overlooked. Calcium and phosphorus usually are border-line deficient, under most ruminant feeding conditions. Limestone, or calcium carbonate (36% calcium), is a common source utilized; dolomitic limestone, containing magnesium (22% calcium), is less desirable. Other sources of calcium include oyster shells (35% calcium) and gypsum (29% calcium). Steamed bonemeal (29% calcium and 14% phosphorus), dicalcium phosphate (25–28% calcium and 18–21% phosphorus), and defluorinated rock phosphate (32% calcium and 18% phosphorus) are additional sources of calcium and phosphorus. Diammonium phosphate (25% phosphorus), phosphoric acid (32% phosphorus), sodium phosphate (22% phosphorus), and sodium tripolyphosphate (31% phosphorus) are additional sources of phosphorus.

Magnesium is deposited largely in bones. A condition known as "grass tetany" is associated with a magnesium deficiency, often occurring in cattle on pasture during cooler seasons of the year. It can be supplied from either magnesium oxide or magnesium sulfate (one form of the latter product is known as "epsom salts"). Potassium usually is not deficient because most forages contain adequate quantities. However, since most grains contain lesser amounts of potassium, fattening cattle on predominantly grain diets might be potassium deficient. Potassium chloride is an excellent source of potassium.

Sulfur seldom is deficient in the diet of ruminants because sulfur-containing amino acids (methionine, cystine, and cystiene) can be used for this purpose. Obviously, sheep have a much greater need for sulfur because of the high content of sulfur in wool. A borderline sulfur deficiency may occur when too great reliance on non-protein nitrogen as a source of protein is used. Various sulfates are intermediate in sulfur availability, but elemental sulfur is almost totally unavailable.

Cobalt, copper, molybdenum, iodine, iron, manganese, nickel, selenium, and zinc sometimes need to be provided to ruminant animals. Mineral deficiency or toxicity in sheep, especially copper and selenium, is a common example of a dietary mineral imbalance (20).

**3.3. Vitamins.** The B-vitamins and vitamin K [84-80-0], $C_{31}H_{46}O_2$, are synthesized by the ruminal microorganisms and their supplementation usually is not necessary. However, there are times when B-vitamin supplementation may be essential. Polioencephalomalacia, sometimes called "circling disease" in cattle, is a nervous disorder, and is alleviated by intravenous injection of thiamine hydrochloride [67-03-8], $C_{12}H_{18}Cl_2N_4OS$, also known as vitamin $B_1$. Niacin supplementation has been shown to alleviate subclinical ketosis, partially increase milk production, and increase average daily weight gain under some conditions (21). Supplementation with choline chloride has been reported to result in higher milk fat percentages and fat-corrected milk yields (21). Dicoumarol [66-76-2], $C_{19}H_{12}O_6$, a metabolic inhibitor of vitamin K, is found in sweet clover and its negative effects are overcome by supplementing with vitamin K.

Vitamins A, D, and E are required by ruminants and therefore, supplementation is sometimes needed. Vitamin A [68-26-8], $C_{20}H_{30}O$, is important in maintaining the integrity of the epithelial tissues of the body. In a deficiency of vitamin A, impaired vision may result, and maintenance and growth of the squamous epithelial cells and bone growth may be impaired (21). Vitamin D

[1406-16-2], $C_{27}H_{44}O$, is important for maintaining proper calcium absorption from the small intestine. Also, vitamin D aids in mobilizing calcium from the bones and in optimizing absorption of phosphorus from the small intestine (21). Supplement with vitamins A and D at their minimum daily recommended rates is suggested because feedstuffs are quite variable in their content of these vitamins.

Vitamin E acetate [58-95-7], $C_{31}H_{52}O_3$, primarily serves as an antioxidant, and is associated closely with selenium. Usually vitamin E is present in typical feedstuffs at levels sufficiently high to meet ruminant requirements, except if the feedstuff has undergone excessive heating or prolonged storage. To ensure that adequate levels of vitamin E are present, alpha tocopherol [59-02-9], $C_{29}H_{50}O_2$, sometimes is added to the diet.

## 4. Performance Modifiers

Several feed additives and implants are available for use with ruminants, which all started with the research of Andrews and Dinusson at Purdue University, which was published in the 1948 Cattle feeders Day Report. That report showed that the implantation of a synthetic female hormone, known as diethylstilbestrol (DES), subcutaneously in finishing beef cattle resulted in about a 10% increase in rate of gain, and a comparable improvement in the efficiency of feed conversion. Cattle feeders utilized this practice for the next one-quarter of a century until its use was declared to be unsafe by the Food and Drug Administration (FDA). However, other hormone-like products had been researched and cleared by the FDA for use by cattle feeders. Table 2 presents the results of a summary of data from 37 trials with steers comparing the value of hormone-like materials for cattle. The data was summarized by Oklahoma State University scientists. Nearly all hormone programs compared resulted in increases in daily gain and also improvement in efficiency of feed conversion. Furthermore, when the effects of all treatments were pooled, use of hormones resulted in significant improvements in rate of gain, feed intake, and efficiency of feed conversion.

Ionophores are additives that alter rumen fermentation and change the relative proportions of fermentative products produced by the bacteria, ie, acetate production decreases and propionate production increases. Ionophores accomplish this by altering the proportions of various ruminal bacteria present. The FDA has approved two ionophores for use for non-lactating ruminants. They are monensin [17090-79-8], $C_{36}H_{62}O_{11}$, and lasalocid [25999-31-9], $C_{34}H_{54}O_8$. Use of effective ionophores usually results in improved efficiency of feed utilization. They may result in increased rate of gain of immature (<16 months of age) cattle consuming a high energy ration. Other potential benefits of feeding ionphores include decreased incidence of lactic acidosis, control of coccidiosis, control of feedlot bloat, and reduction in the number of face fly and horn fly larvae in feces (23). Tables 3 and 4 present data on the effect of feeding ionphores to cattle.

Direct-fed microbials are feed additives composed of microbes and/or ingredients to stimulate microbial growth (27), which allegedly results in more favorable microbial population (30). This could result from changing the gut

Table 2. **Weighted Least-Square Means for Change in Performance from Implanting Hormone-Like Products in Steers[a]**

| First implant | Reimplant | ADG[b] kg | FI[b] kg | FE[b] kg/kg |
|---|---|---|---|---|
| Compudose | None | 0.15[c] | 0.40[c] | – 0.48[c] |
| Compudose + Finaplix | None | 0.24[c] | 0.47 | –0.61[d] |
| Compudose + Finaplix | Finaplix | 0.21[c] | 0.18 | –0.39[c] |
| Finaplix | None | 0.16[d] | –1.74[d] | –1.02 |
| Finaplix | Finaplix | 0.03 | –0.13 | –0.24 |
| Ralgro | None | 0.12[c] | 0.28 | –0.41[c] |
| Ralgro | Ralgro | 0.17[c] | 0.90[c] | –0.29[c] |
| Ralgro | Synovex | 0.26[c] | 0.77[d] | –1.16[c] |
| Ralgro + Finaplix | None | 0.10 | –0.14 | –0.46 |
| Ralgro + Finaplix | Ralgro + Finaplix | 0.11 | 0.77 | –0.01 |
| Revalor | None | 0.19[c] | 0.47[c] | –0.52[c] |
| Revalor | Revalor | 0.32[c] | 0.81[c] | –0.95[c] |
| Revalor | Synovex | 0.22[c] | 0.64 | –0.73[c] |
| Synovex | None | 0.20[c] | 0.31[d] | –0.44[c] |
| Synovex | Finaplix | 0.29[c] | 0.53 | –0.82[c] |
| Synovex | Revalor | 0.22[c] | 0.64 | –0.75[c] |
| Synovex | Synovex | 0.24[c] | 0.67[c] | –0.56[c] |
| Synovex | Synovex + Finaplix | 0.33[c] | 0.70[c] | –0.66[c] |
| Synovex + Finaplix | None | 0.33[c] | 0.46[c] | –0.90[c] |
| Synovex + Finaplix | Finaplix | 0.13[c] | 0.07 | –0.55[c] |
| Synovex + Finaplix | Synovex | 0.30[c] | 0.54 | –0.45[c] |
| Synovex + Finaplix | Synovex + Finaplix | 0.31[c] | 0.65[c] | –0.74[c] |
| | *Average* | *0.23*[c] | *0.52*[c] | *–0.56*[d] |

[a] See Ref. 24.
[b] ADG = average daily gain; FI = feed intake; FE = feed per unit of gain. Change in ADG, FI, and FE: within-study comparisons calculated as $ADG/FI/FE_{(implant)}$ minus $ADG/FI/FE_{(nonimplanted,\ controls)}$.
[c] Change by implanting is unequal to 0 ($P < 0.01$).
[d] Change by implanting is unequal to 0 ($P < 0.05$).

Table 3. **Effects of Ionophores on Performance of Feedlot Cattle[a]**

| | Ionophore | | | | | | |
|---|---|---|---|---|---|---|---|
| Item | None | Laidlomycin | Lasaalocid | Monensin | monensin + Tylosin[b] | Tylosin[b] | MSC[c] |
| dose, mg/hd/day | 0 | 85.8 | 285.9 | 272.2 | 263.2 | 104.0 | |
| dose, gm/ton | 0 | 8 | 29 | 28 | 27 | 10 | |
| means | 49 | 37 | 22 | 29 | 33 | 20 | |
| cattle, no. | 1556 | 1137 | 1290 | 1042 | 1200 | 665 | |
| ADG, kg | 1.39[d] | 1.46[d] | 1.38[d] | 1.38[d] | 1.39[d] | 1.39[d] | 0.089 |
| DMI, kg/day | 9.34[d] | 9.33[d] | 8.91[d] | 8.81[d] | 8.73[d] | 9.40[d] | 2.238 |
| feed/unit gain | 6.81[d] | 6.48[d] | 6.52[d] | 6.44[d] | 6.35[d] | 6.86[d] | 1.783 |
| improvement, % | | 4.8 | 4.2 | 5.4 | 6.8 | | |

[a] A summary of 67 finishing trials and 55 pasture (or on forage in confinement).
[b] Tylosin dose: 98 mg/phead/pday
[c] Mean square error of weighted (observations/mean) ANOVA.
[d] Means differ ($P < 0.05$).

Table 4. **Effect of Ionophores and Bambermycins on Performance of Grazing Cattle**[a]

| Item | Control | Bambermycin | Lasalocid | Monensin | MSE[b] |
|---|---|---|---|---|---|
| dose, mg/hd/day | 0 | 25 | 188 | 167 | |
| means | 70 | 10 | 14 | 47 | |
| cattle, no. | 1885 | 223 | 311 | 1329 | |
| daily gain, kg | 0.64[c] | 0.78[c] | 0.78[c] | 0.75[c] | 0.068 |

[a] See Ref. 26.
[b] MSE = means-square error, as listed for Table 3.
[c] Means differ ($P < 0.05$).

microflora and reducing *Eschuichia Coli*, producing antibiotics, synthesizing lactic acid, colonizing the intestinal mucosa, or prevention of toxic amine synthesis in the gut (31). Yeasts, especially *Saccharomyces cerevisiae* and *Aspergillus oryzae*, have been researched as direct-fed antibiotics for cattle (5). Several experiments have shown beneficial changes in ruminal fermentation and/or increases in fiber digestion after adding direct-fed antibiotics to diets (5). However, other reports (32) cite conflicting results as to the benefit of adding direct-fed microbials to ruminant diets.

The author of this section was the first to demonstrate improvement in rate of gain from the feeding of low levels (75 mg/head, daily) of chlortetracycline (aureomycin) and oxytetracycline (terramycin) in the 1950s, at Purdue University. The modus operandus of the positive effect of supplemental antibiotics in beef cattle has not been explained. Possible explanations that have been advanced include decreased activity of microbes having a pathogenic effect on the animal, decreased production of microbial toxins, decreased microbial destruction of essential nutrients, increased synthesis of other growth factors, and increased nutrient absorption because of thinner intestinal wall (29). Antibiotics fed at subtherapeutic levels might help alleviate stress on an animal (5). Much interest has been aroused because of the theory that the use of antibiotics in animal nutrition might be responsible for the development of “super-bugs” for humans in which case antibiotics might lose their potency in human medicine.

A problem common to animals consuming a high energy diet or lush, immature legume vegetation is increased susceptibility to bloat. Bloat is a condition where gas either is formed too rapidly or else the animal is not able to release such gas sufficiently rapidly. Either or both conditions leads to a gas build-up in the rumen. Excessive foam build-up in the rumen also may play a role in this condition. Anti-foaming agents available to prevent this condition include silicones, detergents, vegetable oils, animal fats, animal mucins, and liquid paraffins (32). Poloxalene [9003-11-6] is an example of a commonly-used surfactant developed primarily to prevent bloat on pastured cattle.

Buffers are used to stabilize ruminal pH at 6.0–6.8. Available buffers include sodium bicarbonate, calcium carbonate (limestone), and bentonite. However, sodium bicarbonate is a most effective buffer and is used more commonly than any other. High concentrate rations are fermented rapidly resulting in a decrease in pH due the production of ruminal acids. The decrease in pH is deleterious to the animal, not only because it slows fermentation, but also because it may result in physical harm, eg, cause ruminal lesions. High energy feedlot diets and dairy diets usually contain sodium bicarbonate to buffer such high energy diets (31,9). High fiber diets benefit little from added buffers because of greater buffering capacity of such diets.

Many ruminal bacteria require one or more branched-chain volatile fatty acids (VFA) for proper growth. The branched-chain VFAs, ie, valeric [109-52-4], $C_5H_{10}O_2$; isobutyric [79-31-2], $C_4H_8O_2$; 2-methylbutyric [623-42-7], $C_5H_{10}O_2$; and isovaleric acids [503-74-2], $C_5H_{10}O_2$, normally are derived from branched-chain amino acids. Thus, ruminal microbial protein may be limited if less than optimal amounts of branch-chained amino acids are present (5). Supplementation with these VFAs have been researched, but results have not been clear-cut (5,28,32). Furthermore, branch-chained amino acids are not so readily available, and so one must plan on feeding protein sources sufficiently degradable that these nutrients can be provided.

Defaunation is a term used to describe the elimination of protozoa from the rumen. Ruminal protozoa conceivably might have both positive and negative effects on animal performance (5,37). Defaunation may increase ruminal microbial efficiency because less methane is produced and less proteolysis occurs (37). However, under some conditions, protozoa may help stabilize the ruminal environment (5). Ruminal protozoa engulf a portion of the starch, slowing down bacterial fermentation, and could play a role in delaying the onset of lactic acidosis. Defaunation can be accomplished using copper sulfate and nonionic and anionic detergents (5). Defaunation is not a common practice in ruminant nutrition, but under certain specific conditions might have a role.

The first part of this section dealt with the use of hormone implants as performance modifiers. Melengesterol acetate (MGA) [2919-66-6], $C_{25}H_{32}O_4$, is a synthetic progesterone that suppresses estrus in heifers. It is effective orally and thus is mixed into a supplement designed to be fed to heifers, causing such treated animals to grow more rapidly and to require less feed per unit of gain (5).

Bovine somatotropin (BST) is a naturally occurring protein hormone produced by the pituitary gland of cattle and is a major regulator of growth and milk production. It is produced in commercial quantity using recombinant DNA technology. Increases in milk production from the use of varying levels of BST (5–50 mg/cow/day) range from 3–6 kg/cow/day. Persistency of lactation is improved. Use of supplemental BST has increased milk production in all breeds of cattle. Bauman and co-workers at Cornell University (39) presented a summary from 340 herds, including 80,000 cows, 200,000 lactations, and 2 million test days, over an 8-year period (January 1990–March 1998). A summary is presented in Table 5.

## 5. Young Animal Feeds

When a ruminant (mammal) is born it consumes colostrum within a few hours. Colostrum contains antibodies from the mother's milk that serve to immunize the neonate against disease (34). Such antibodies can be absorbed by the neonate only within the first few days of life; there is no placental transfer of antibodies in ruminants (34).

Table 5. **Effect of BST on Production in Dairy Herds in the Northeastern United States**[a]

| | January, 1990–February, 1994 | | | July, 1994–March, 1998 | | |
|---|---|---|---|---|---|---|
| | Control | BST | | Control | BST | |
| no. herds | 176 | 164 | | 176 | 164 | |
| cows/herd, av. | 74.9 | 84.9 | | 75.7 | 90.5 | |
| | | | Difference | | | Difference |
| milk/day, kg | 27.2 | 28.7 | +5.5% | 28.8 | 33.3 | +15.6% |
| butterfat/day, | 998 | 1043 | +4.7% | 1048 | 1179 | +12.5% |
| protein/day, | 871 | 916 | +5.2% | 907 | 1048 | +15.5% |
| somatic cell count (linear score) | 3.22 | 3.10 | | 3.08 | 3.17 | |
| av. age of cows, years | 4.56 | 4.34 | | 4.33 | 4.14 | |

[a]See Ref. 39.

The rumen is not functional at birth and ingested milk is shunted to the abomasum. Within one to two weeks after birth the neonate will start to consume solid feed if offered. A calf or lamb that is nursing tends to nibble its mother's feed. An alternate method of raising the neonate is to remove it from its dam at a very early age, $<1$ week. The dairy calf, typically follows such procedure, in order that the dam's milk may be channeled into commercial trade. Such neonate must be supplied with complete supplementation provided by a milk replacer. Sources of milk replacer protein traditionally have been skimmilk, but may also include soybean protein, fish protein concentrates, field proteins, pea protein concentrates, and yeast proteins (4).

Approximately 8 weeks after birth, the ruminant has developed a fully functional rumen, capable of extensive fermentation of feed nutrients (4). The rate of development of the ruminal environment depends on the amount of milk consumed by the neonate in relation to its growth requirements, the availability and consumption of readily digestible feedstuffs, and physical form of feedstuffs (4). The rumen will develop much faster when hay is consumed than when only milk and grains are consumed (36). Concentrates, ie, high cereal grain diets, increase the absorptive surface of the rumen, but ruminal size and musculature develop much more slowly with a concentrate diet than with a forage diet (4).

Several sources of energy feeds can be utilized by the neonate. Lipids generally are $\sim$90% digestible (4), and lipid sources include milk fat, tallow, and corn oil. Carbohydrates are another source of available energy. Lactose [63-42-3], glucose [50-99-7], and galactose [26566-61-0] are utilized efficiently, whereas starch, maltose [69-79-4], sucrose [57-50-1], and fructose [57-48-7] are not utilized as well by the young ruminant (4). Hydrolyzed starch has been used successfully to replace a portion of the energy in diets fed to young ruminants (4). Protein sources given young ruminants just beginning to consume solid food should contain high quality (good balance of amino acids) from plant sources, or else a combination of such with milk by-products (18).

Little research is available for delineating levels of vitamins and minerals required by the young ruminant. However, it is common to supply calcium, phosphorus, trace-mineralized salt, and vitamins A, D, and E (4). Prior to the time the rumen becomes functional, B-vitamins and vitamin K will be needed.

Creep feeding often is used in the production of beef cattle. This practice involves offering feedstuffs to the young, that are not accessible to the dam. Since the dam's milk is rich in protein and minerals, the greatest supplemental need is for energy. Young calves relish such high energy grains as shelled corn and other similar grains. If it is possible, allowing young calves access to pasture where the dams are not admitted is another form of creep feeding.

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