General Session I

Dr. Keith Sterner, *presiding*

Ionophores, Buffers and Protein for Feedlot Cattle

Fredrick N. Owens, *Ph.D.*
Animal Science Department
Oklahoma State University
Stillwater, Oklahoma 74078

In the past decade, a number of new and different feed additives which will improve performance or efficiency of feedlot cattle have been discovered and are widely fed. New information on ionophores, buffers and protein supplementation have modified diets of feedlot cattle. This manuscript will review recent developments in dietary management to avoid metabolic problems and improve performance of feedlot cattle covering the use of ionophores and buffers in diets and bypass protein. Drug clearances and levels are listed in the Feed Additive Compendium (2) and will not be restated in this paper.

Ionophores for Feedlot Cattle

Today, over 90% of the cattle in feedlots are being fed an ionophore—monensin or lasalocid. Rapid adoption of the practice of feeding ionophores attests to their effectiveness and economic benefits. By definition, an ionophore is a compound which makes cations (Na+, K+, Ca++) soluble in lipid. Ionophores shuttle cations through lipid membranes of cells and alter metabolism. As intestinal coccidia have only a limited energy reserve to restore cation status, all ionophores are active coccidiostats. Ionophores are poorly absorbed, but they alter microbial metabolism in the rumen. Two ionophores are widely used today, and several other ionophores are being field tested.

Monensin

First reported in 1967, monensin was successfully marketed as a coccidiostat for poultry under the trademark "Coban". It became available for cattle under the trademark "Rumensin". Patented by Elanco, Inc., Greenfield, IN, monensin is widely used in poultry diets. In contrast with other coccidiostats, monensin feeding has not resulted in development of resistant coccidial strains, and low absorption avoids toxicity to the host animal. The horse is more subject to ionophore toxicity than other farm animals.

Similar to all other ionophores reported to date, monensin is synthesized by a Streptomyces strain. Screening with ruminal fluid revealed that monensin alters fermentation. Like other ionophores, monensin increases the proportion of propionic acid and decreases the proportion of acetic acid as end-products of fermentation in the rumen. This change decreases loss of energy in the form of the expired gas, methane. Thereby, more energy from the fermented feed becomes available to the ruminant and less is lost as methane. Extensive national testing of the safety and efficacy of monensin culminated in its FDA approval to increase the efficiency of feed use by feedlot cattle (1976) and pasture cattle (1978). Combination clearance with the antibiotic Tylan to control liver abscesses was granted in 1978. The compound also will reduce the amount of feed needed for wintering range cattle, increasing the carrying capacity of lower quality pastures. With better quality pastures, rates of gain of grazing cattle are increased with monensin.

Monensin is cleared for feeding at levels between 5 and 30 g per ton of feed. At lower levels of monensin in the diet, rate of gain may be increased (table 1). At higher levels, monensin reduces feed intake and gains, so that levels above 30 g per ton will not improve feed efficiency.

Feed efficiency appears to be maximized at 30 g per ton. But when cost of feed is low relative to yardage and interest, a feeding a lower level of monensin may be more economical so that a higher rate of gain is obtained. With higher roughage diets, higher monensin levels appear most useful.

Almost invariably, monensin feeding for periods longer than 60 days improves efficiency of feed use. The 19 trial summary by Elanco (11) shown in table 1 presented an average improvement of 10.6% for growing and finishing trials. A more recent summary by Wagner (54) for feedlot cattle listed a gain increase of 2.5% and an efficiency improvement of 7.2%. A summary of Oklahoma State feedlot trials with higher concentrate feedlot diets (table 2) shows an efficiency improvement of 4.9%.

No change in carcass characteristics has been detected with monensin feeding, though the incidence of liver abscesses may be increased. Antibiotic feeding controls this

TABLE 1. Nineteen Trial Feedlot Summary (11).

	Rumensin, g per ton				
	0	5	10	20	30
Pens, No.	63	31	56	61	60
Daily gain, lb.	2.29	2.39	2.37	2.33	2.28
Daily feed, lb.	21.5	20.8	20.8	19.8	19.2
Feed/gain	9.46	8.80	8.83	8.57	8.46

problem. Economics favors ionophore feeding. A feedlot steer gaining 300 pounds is fed about $3 worth of monensin which will save $11 to $16 worth of feed.

Though monensin and other ionophores improve feed efficiency, the proposed mechanisms of action are diverse and remain to be defined. First, reduced methane loss with monensin can explain only about a 2% improvement in feed efficiency. Second, monensin generally increases digestibility of energy, from 0 to as much as 9%. This effect, most apparent with roughage diets and coarse grains, is not detected with steam flaked grains. Third, monensin appears to spare dietary protein. Possibly it reduces the amount of protein degraded to ammonia in the rumen or spares certain amino acids at the tissue level. Thus, monensin may be especially useful with low protein diets.

Fourth, monensin is reported to reduce the incidence of feedlot problems with coccidiosis, acidosis, founder and sudden death. Monensin inhibits production of lactate by bacteria in the rumen. Reducing feed intake may have helped avoid some problems, as well. Fifth, monensin may reduce the maintenance energy requirement of cattle by altering tissue metabolism. Some monensin reaches the liver and might alter energy expenditure by the sodium pump. Though the sodium pump in lean tissue uses a great deal of energy, no evidence to support altered tissue metabolism with feeding of monensin has been demonstrated.

Lasalocid

This ionophore was developed and is marketed by Hoffman-LaRoche, Nutley, NJ, under the trademark Avatec for poultry and Bovatec for feedlot cattle. It appears to have many of the attributes of monensin though it is less selective for sodium and potassium ions and will aid transport of calcium ions as well. Compared with monensin, lasalocid appears to depress feed intake less at higher levels in the diet. Thereby, rate of gain and efficiency of feed use are both improved with lasalocid. Mechanism of action are probably the same as for monensin.

Ionophores under test

Salinomycin (A. H. Robbins, Richmond, VA), Lysocellin (International Minerals and Chemical Corp., Terra Haute, IN), Narasin (Elanco Inc., Greenfield, IN), ICI 139603 (Imperial Chemical Industries, Macclesfield, England) and Laidlomycin (Syntex Research, Palo Alto, CA) are among the ionophores being tested by various companies for safety and efficacy. As they differ in ion specificity, their actions may differ slightly. Much more research is needed concerning the effectiveness of combinations of ionophores with other antibiotics and glycopeptides.

Ionophores resistance

Early microbiological studies indicated that inophores were a very selective antibiotic and reduced the population of certain sensitive species of bacteria in the rumen. Later work with monensin has suggested that ionophores act as chemicals and inhibit certain chemical reactions by bacteria, and when the ionophore is removed, the shift in endproducts of fermentation is immediate, not after the time needed for selection of a new population of bacteria. Recently, bacterial strains resistant to monensin have been detected. Bacteria appear more resistant to ionophores when potassium concentrations are high (9).

Even though bacterial resistance to ionophores can be detected, the ionophores do not appear to have lost their effectiveness in cattle feeding. Ionophores appear as useful in cattle feeding today as 10 years ago when experimentation began.

This suggests that if resistance has developed, it is not markedly reducing the beneficial effects of ionophores. However, resistance could explain a portion of the greater benefit of monensin with low protein (low potassium) diets and might indicate that ionophores may be less effective with higher potassium levels.

Buffers and Acidosis

Buffers, by definition, are compounds which resist a shift in pH when acids or bases are added to a solution. The

TABLE 2. Ionophore trial results from Oklahoma State University.

	Daily Gain			Feed/Gain			Feed Intake		
	Control	Drug	Change	Control	Drug	Benefit	Control	Drug	Change
Monensin	lbs.	lbs.	%			%	lbs.	lbs.	%
972 Cattle MEANS	3.19	3.20	0.11	6.17	5.87	4.87	19.24	18.41	– 4.32
LASALOCID									
320 Cattle MEANS	2.81	2.96	5.31	7.04	6.66	5.37	19.12	19.02	– 0.52
SALINOMYCIN									
344 Cattle MEANS	2.87	3.13	9.25	6.93	6.40	7.62	19.55	19.89	1.75

primary buffers found in the body and the digestive tract are bicarbonate and phosphate. Acid accumulates in the rumen when ruminal bacteria rapidly digest soluble carbohydrates to lactic acid. When large amounts of lactic acid are absorbed, metabolic acidosis, laminitis and death result. Lactic acidosis is one of the major problems with feeding of high concentrate diets to cattle. Acidosis usually occurs when cattle are first exposed to concentrate diets or after a period of fasting. Therefore, acidosis often reflects a management problem.

Lactic acidosis occurs with high concentrate diets and overwhelms the buffering capacity in the rumen for two reasons. First, the production of lactate by ruminal bacteria is highest when carbohydrates are rapidly fermented. With steam flaked diets and with wheat grain, starch rapidly yields sugars which in turn are rapidly fermented to lactic acid. Secondly, cattle fed concentrate diets generally consume their feed rapidly and ruminate little. The amount of saliva added to the feed is proportional to chewing and rumination time. Saliva of cattle is basic and contains a high level of bicarbonate. Saliva satisfactorily buffers volatile fatty acids produced from digestion of forage in the rumen. As a substitute for buffers provided by saliva, cattlemen often add buffers or bases to the diet for cattle in an attempt to prevent lactic acidosis.

Types of Buffers

The most commonly fed buffer is sodium bicarbonate. Calcium carbonate (limestone), magnesium oxide, phosphorus salts and other minerals can be fed to neutralize or buffer acids in the rumen. Compounds which are soluble in water are more active in the rumen than compounds which are less soluble. Some workers suggest that poorly soluble buffers are active in the intestines of cattle, but evidence to support this idea is lacking. Buffers have found wider use in dairy than in beef cattle diets. Some buffers may help maintain the percentage of fat in milk as well as alleviate acidosis.

Addition of buffers to beef cattle diets has received a great deal of applied research attention. Sodium bicarbonate and limestone supplementation have been subjects of many feeding studies and several excellent reviews and symposia (22, 32, 41, 53, 56).

Benefits from buffer feeding differ widely, probably because the more basic answers about site and actions of buffers on the digestive or metabolic process in cattle remain largely unknown. Field trials from the past 5 years have been summarized to determine the value of addition of buffers to diets for feedlot cattle. Results prior to 1977 are not included since earlier bicarbonate trials have been summarized previously (53). Further, monensin was not widely fed in trials reported prior to 1979. Field trial results will be discussed first followed by consideration of more basic studies which may identify the reasons behind variable responses to buffers in diets for finishing beef cattle.

Twenty-four comparisons with sodium bicarbonate supplementation have been published in Cattle Feeders' Day reports from 9 states. On the average, 1% sodium bicarbonate (range = .4 to 2.5%) was added to a 71% concentrate diet (range = 18 to 95%) and fed to 33 cattle per treatment group (10 to 98) weighing a mean of 652 pounds at the start of the trial (422 to 850 pounds) for 122 days (73 to 195 days). Mean response to bicarbonate supplementation weighted by animals numbers is presented in table 3.

TABLE 3. Influence of bicarbonate supplementation on feedlot performance 1978 to 1982 (24 comparisons w/791 cattle).

	Diet		Percent
	Control	Bicarbonate	Change
Daily gain, lbs.	2.67	2.69	+ .52
Daily feed, lbs.	17.5	17.7	+1.03
Feed/gain	6.52	6.53	— .22
Met. energy[a]	2.94	2.93	— .29

[a] Calculated from feed intake, gain and weight.

Averaged over these 24 comparisons from 8 different states, it appears that addition of bicarbonate to the diet increased rate of gain and feed intake slightly, but bicarbonate feeding did not improve feed efficiency.

Since acidosis usually occurs when cattle are first being adapted to a high concentrate diet, buffers should be most useful early in a feeding trial. To check this idea, performance of cattle in these feeding trials was divided into early and late segments as presented in table 4.

TABLE 4. Influence of bicarbonate supplementation on feedlot performance in the early or late portions of the trial (4 comparisons early and 2 comparisons late).

	Period	
	Early	Late
	Bicarbonate response, %	
Daily gain, lbs.	+3.7	+3.5
Daily feed, lbs.	0.0	+3.8
Feed/gain	+4.4	−0.1

Though few trials are available to test this comparison, greater benefit in gain and feed efficiency were noted during the early portion of the feeding trial. Later in the trial, feed intake appeared to be increased with buffer feeding. Though acidosis may be more common early in a feeding trial, this is also the period when more roughage is fed and protein may be marginal. So this difference could also be associated with effects of buffers on fiber digestion or protein metabolism as will be discussed later.

Another acid neutralizing material, limestone, is often fed above the level needed to meet the calcium requirement of cattle to serve as a "buffer". Limestone is less soluble in rumen fluid than bicarbonate and has been suggested by

some to be an intestinal buffer though evidence for this speculation is lacking. Calcium or limestone supplementation of feedlot diets has been evaluated in 37 reported comparisons from 7 states since 1979. On the average 1% limestone (.26 to 2.06%) was added to a 69% concentrate diet (18 to 85%) and fed to 25 animals per treatment (10 to 192) with an initial weight of 672 pounds (481 to 1061 pounds). Weighted means are presented in table 5.

TABLE 5. Influence of limestone supplementation on feedlot performance (37 comparisons w/983 cattle from 1978 to 1983).

	Diet		Percent
	Control	Limestone	Change
Daily gain, lbs.	2.61	2.64	+ .90
Daily feed, lbs.	18.2	18.0	−1.29
Feed/gain	7.02	6.86	+2.22
Met. energy[a]	2.97	3.02	+1.70

[a] Calculated from feed intake, gain and weight.

On the average, feed efficiency was increased by 2.2% with added limestone while feed intake tended to decrease (1.3%). Rate of gain was increased a mean of 0.9% with added limestone.

Also, trials were subdivided on the basis of level of calcium in the unsupplemented diet. Basal diets in these trials contained a mean of .32% calcium (.15 to .46%) as compared to an estimated requirement listed by the NRC of .28 to .46% for various classes of finishing cattle. An interaction between the benefit from limestone and the basal level of calcium in the diet was apparent. The greatest response to limestone supplementation was with a very low (.15%) calcium diet. With such diets, supplemental limestone increased gain and efficiency by over 5%. In contrast, when the basal diet contained over .43% calcium, no benefits in gain or efficiency were noted from added limestone. Supplementation to at least this level appears justified. But high levels of calcium (over 1% of the diet) depressed feed intake markedly in certain studies.

Buffers and Ruminal pH

Sodium bicarbonate increased ruminal pH in about 70% of the trials reviewed by Trenkle (53). By comparison, pH responds little to dietary limestone. Ruminal pH is the balance between 1) fermentation acids produced within the rumen or consumed with feeds such as silages, 2) fed bases or bases released in the rumen (hydroxides and ammonia), and 3) the buffering by feedstuffs, salivary components and dietary supplements. Buffering agents help resist pH change with added acid or base. Dietary buffers may act directly or may modify ruminal pH through altering either rate of fermentation or time for fermentation of starch and soluble nutrients in the rumen. Feedstuffs such as legume leaves and forages also act as buffers. Consequently, type of feedstuff, specific buffer and concentration employed, level of feed intake, previous nutritional programs and feeding regime may all influence the response of animals to added buffers.

The rumen normally contains a number of "natural" buffering materials. The contribution of any substance to ruminal buffering is dependent on its concentration in ruminal fluid plus its pK, the point of maximal strength. Bicarbonate, phosphate and volatile fatty acids (VFA) are the primary ruminal buffers (8).

Mixed saliva has its maximum buffering capacity between pH 7.5 and 5.5. (3). Maximum buffering capacity of ruminal contents, in contrast, is below pH 5.0 (21), similar to the pK values of acetate, propionate, butyrate and lactate (4.8, 4.9, 4.8 and 3.9). Lactate, because of its low pK, reduces ruminal pH more drastically than other ruminal acids. Since ruminal bacteria which use lactate are inactive below a pH of 5.5, lactate accumulates, further reducing pH to about 4.

Type of Feedstuff

Feeds differ in their inherent buffering capacities and are active in ion exchange within the rumen. Salts, such as KCl, cell wall-ion complexes and organic acids in feeds also influence ruminal resistance to pH change. Legumes have greater buffering capacity than grasses. In silages, ammonia and amides liberated from protein help neutralize acids. Ammonia liberated from amino acids or urea will increase ruminal pH (21). Ruminal pH also may be elevated when ammoniated crop residues are fed.

The amount of saliva added to feedstuffs during eating and rumination differs, and since saliva is a major source of ruminal buffers, this influences ruminal pH. The amount of saliva added appears proportional to the amount of time spent eating and ruminating. Salivation and moisture content of the feed are inversely related, and salivary buffer secretion appears much lower with silage than with the same crop fed as hay or grazed fresh.

Both cereal grains and corn silage contain only low amounts of alkaline minerals. Coupled with a rapid fermentation rate, these common feedlot diet ingredients predispose animals to a low ruminal pH. Pelleted and ground feeds and low roughage diets reduce salivary buffer secretion. In contrast, whole or coarsely cracked grains produce fermentation acids more slowly, permitting more time for addition of saliva to the rumen. Use of higher fiber levels and dry, less processed feedstuffs reduce the potential for a pH response to dietary buffers.

Buffer Type and Level

For a buffer to neutralize fermentation acids, it must be distributed or circulated to come into contact with acids. The more soluble the buffer, the greater its immediate action within the rumen. In contrast to some other buffering materials, sodium bicarbonate is very soluble in ruminal fluid. Bicarbonate increases ruminal pH more with concentrate than roughage diets (44), partly because pH

changes are greater when the pH is further from the pK of the buffer.

Whether limestone acts as a ruminal buffer is questioned by its low solubility in ruminal fluid. Variable response to limestone supplementation has been attributed to rate of reactivity. Either too rapid release of CO_2 or too slow neutralization of acid may be undesirable. Though limestone is typically over 95% calcium carbonate, ruminal activity may vary. Rate of reactivity appears related to rate of movement of material into solution and can vary from seconds to hours or days. Solubility of limestone is dependent on chemical composition (Mg level), crystalline structure, particle size and possibly other factors (16). Rate of reactivity may vary within and between mining quarries.

Trenkle (53) proposed that ruminal activity may be exhibited by limestone despite its low solubility and pH increases with limestone feeding have been reported in some trials (10, 21). No alteration in ruminal pH was reported in studies by Emery (10), Rogers *et al.* (45) and Haaland and Tyrrell (20). Explanation of these different findings on the basis of intake level or fermentation rate is not possible.

The influence of particle size and specific gravity or hydrated density of insoluble buffers on ruminal pH at various locations within the rumen have not been fully investigated. Coarse particle, high density limestone may separate from fibrous material in the rumen, and settling would reduce the potential for buffering of the total rumen. More homogeneous ruminal contents, as found with higher concentrate diets may cause buffers to be more thoroughly mixed in the rumen.

Post-ruminal pH Effects

Increased fecal pH and intestinal pH at slaughter led some workers to suggest that dietary limestone will increase pH of the small intestine. Fecal pH has been used as an index of pH in the small intestine. Amylase activity is fastest at a pH of about 6.8, so an intestinal pH near 6.8 should maximize the rate of starch digestion. Consequently, pH modification of the small intestine to maximize starch digestion has become of interest based on the assumption that amylase activity is the limiting factor.

This concept has two basic flaws. First, intestinal contents are strongly buffered with CO_2. So pH of the small intestine will not change with added buffers or bases (29, 57). Secondly, adding amylase to the small intestine has failed to increase starch digestion. This indicates that factors other than amylase activity, such as particle size, limit starch digestion from cereal grains more than amylase activity.

Additional ruminal changes with dietary buffers can occur in rate of fluid and particle passage, levels of VFA and fiber digestion.

Passage of fluid from the rumen increases with $NaHCO_3$ addition to high concentrate diets fed ad libitum (23, 43). Faster fluid passage appears to be due to osmotic pressure. Increased ion concentration from added soluble buffers will increase influx of fluid through the ruminal wall. Water consumption often increases as well, since urine output is usually increased with the extra sodium.

Not all buffers behave like bicarbonate. Several studies have reported no significant change in ruminal dilution rate with added limestone (20, 45, 46).

Increasing fluid dilution rate with $NaHCO_3$ has several effects. Efficiency of microbial protein synthesis, at least of the free floating microbes, should increase as microbes are forced to multiply at a faster rate and spend less time at maintenance prior to passage out of the rumen. Faster turnover may alter metabolic pathways of microbes as well. But increased fluid passage does not necessarily increase the total output of microbial protein, since substrates will be flushed out as well. Faster fluid flow will comcomitantly elevate outflow of the more soluble, suspended and incompletely degraded starch, protein, and fiber, leaving coarser, less dense materials behind. Extent of increased passage of various nutrients with $NaHCO_3$ added to high grain diets at high levels of intake remains unknown. the overall balance between rate of digestion and time for digestion with added buffers probably differs with specific dietary and feeding conditions.

With a high roughage diet, particulate outflow from the rumen may be limited by coarseness of fiber. If the pH is more optimal for fiber digestion, and fiber is digested more rapidly, dilution rate of solid material should increase when ruminal pH is increased with buffers. An increased rate of fiber clearance should permit feed intake and productivty to increase if ruminal fill is the factor limiting feed intake.

Microbial metabolic pathways or populations can be altered by buffers. Usually acetate concentration increases and propionate concentration decreases. This change is associated with restoration of fat content of milk which may be depressed when concentrate diets are fed. However, VFA changes with sodium bicarbonate may vary with ruminal pH, liquid and solids flow rate and the microbial population.

Rate of cellulose digestion is decreased when pH falls below about 6.1 continuously or between meals (18). Lower cellulase activity with acid conditions or altered metabolism, decreased growth rate and/or numbers of cellulolytic microbes may be responsible (28, 33). Depressed fiber digestion with medium to high concentrate diets probably involves a combination of the above factors. Ruminally soluble buffers, such as $NaHCO_3$ increase total tract fiber digestion (13, 43, 45, 51).

Limestone has increased digestibility of fiber in some trials (45, 46, 57), but not in others (29, 52).

Protein Digestion

The proteolytic activity in bacterial cultures will increase dramatically as pH increases (14). solubility and susceptibility to microbial attack of some proteins also will increase with pH (26, 53). Greater rates of ruminal digestion of plant proteins (soybean meal, cottonseed meal, alfalfa meal) with roughage than concentrate diets are often evident, possibly

associated with a higher ruminal pH, causing increased protein solubility at the higher pH or to greater protein exposure due to more extensive digestion of fiber from plant cell walls.

An elevated pH and fiber digestion rate should decrease protein bypass more with plant materials (soybean meal, cottonseed meal, alfalfa meal) than animal or non-fibrous proteins (19).

Starch Digestion

Total tract starch digestion often has increased with limestone feeding (45, 46, 52). Laudert and Matsushima (29) reported an increase small intestinal digestibility of organic matter and starch with limestone supplementation while total tract values remained unchanged. Increased ruminal digestion of starch with limestone feeding was observed in 4 of the 6 Oklahoma trials (40), and in 3 of the 6 comparisons, small intestinal digestion of starch entering the small intestine was numerically increased.

Interactions of Buffers with Ionophores

Feed additives may act by similar or different mechanisms. Thus their effects may not be summative. For example, both monensin and lasalocid aid in prevention of acidosis and may alter the need for and benefit from dietary buffers and bases. On the other hand, growth stimulating implants act through a different mechanism and appear completely summative with digestive tract modifiers such as buffers and ionophores. Trials evaluating the effects of feed additives on performance of feedlot cattle published in Cattle Feeder's Day reports from across the U.S. over the past 5 years have been searched to more fully understand the interactions of ionophores and buffers and bases.

Bicarbonate and Monensin

Of the 24 trials discussed earlier, 14 had monensin also included in the diet and 10 noted no addition of monensin. These trials were subdivided into two sets for comparison (table 5A).

TABLE 5a. Influence of bicarbonate supplementation on feedlot performance with or without monensin percent (14 comparisons with monensin and 10 comparisons without monensin from 1978 to 1982).

	Monensin	
	Present	Absent
	Bicarmonate response, %	
Daily gain, lbs.	+2.3	−1.4
Daily feed, lbs.	+0.1	+0.7
Feed/gain	+2.3	−2.0
Met. energy[a]	+1.0	−1.3

a Calculated from feed intake, gain and weight.

Gain and efficiency of feed use were increased slightly in the absence of monensin, but the combination of bicarbonate with monensin reduced both rate and efficiency of gain. Since monensin helps prevent acidosis and often will increase ruminal pH slightly, this ionophore may remove the need for added bicarbonate. Also, the two appear to have opposite actions on ruminal outflow and might cancel each others action at that site. Though overall, little benefit was apparent for bicarbonate, certain diets and cattle might benefit. But the bicarbonate benefit appears to be diminished by including monensin in the diet.

Limestone and Monensin

In 23 of the 37 limestone supplementation trials, ionophores were fed. Again, an interaction between ionophore feeding and limestone was apparent (table 6).

TABLE 6. Influence of limestone supplementation on feedlot performance with or without ionophores present (23 comparisons with ionophores and 14 comparisons without from 1978 to 1983).

	Ionophore	
	Present	Absent
	Limestone response, %	
Daily gain, lbs.	+3.1	+0.9
Daily feed, lbs.	−1.4	−0.9
Feed/gain	+4.6	+1.5
Met. energy[a]	+2.6	+1.1

a Calculated from feed intake, gain and weight.

Feeding monensin reduced the benefit of limestone supplementation. Both may increase starch digestibility, but animal performance effects do not appear additive.

In conclusion, benefits observed with certain feed additives such as monensin, limestone and bicarbonate are not complementary. In certain cases, the combination may prove deleterious. Only thorough examination of results of a variety of trials can reveal which compounds may act harmoniously and which act antagonistically.

In summary, benefits from addition of $NaHCO^3$ to high grain finishing diets are not apparent from long term feeding studies at a number of experiment stations. A slight increase in fiber digestion in the rumen may help clear fiber from the rumen during adaptation to high concentrate diets. $NaHCO^3$ may play a role in high grain feeding programs as a management tool to reduce the incidence of acidosis through direct action of the buffer or indirect action reducing meal size. Buffers may help alleviate certain management problems of diet mixing, animal crowding and intermittent feeding which may cause acidosis. But for prevention of acidosis, the ionophores appear to offer greater promise than buffers. With questionable feeding or management conditions in feedyards where acidosis is a problem, buffers may prove helpful. $NaHCO^3$ appears most useful with mixed diets or during adaptation to high grain feeding

programs.

Supplemental limestone may increase starch digestibility by a few percentage points. Though the site of limestone action on starch digestion remains uncertain, most studies suggest that ruminal starch digestion is increased with supplemental limestone. In field trials, some benefits are due to the added calcium ion and not to buffering action of limestone.

High levels of either bicarbonate or limestone may depress feed intake. But when feed intake increases when limestone or bicarbonate is added to a diet, rate and efficiency of gain will usually increase. A response in feed intake probably is the best indicator of benefit from added buffer. If added buffers increase feed intake, the buffer will probably improve rate and efficiency of gain. Finally, ionophores and buffers may not act in a summative manner. Some of the benefits derived from feeding buffers also may be obtained by feeding ionophores to beef cattle.

Protein

Amino acids for cattle come from two sources—microbial protein, which is made by bacteria in the rumen, and dietary protein, which bypasses or escapes fermentation in the rumen. Microbial protein can be synthesized from non-protein nitrogen compounds such as urea. The amount of bacterial protein systhesis in the rumen determines how much of the dietary protein can be provided by urea, while the amount of bypass determines the value of various protein sources for cattle.

Microbial Requirements

About 75% of the carbohydrate digested by ruminants is fermented by microbes in the rumen. During fermentation, volatile fatty acids, ammonia, methane and CO_2 are released and energy is liberated for microbial growth and multiplication. A wide variety of microbial types, including many species of anaerobic bacteria, protozoa and even fungi thrive in the rumen. Swept out of the rumen to the abomasum and small intestine with fluid and particles, these microbes typically furnish about half of the protein (amino acids) needed by cattle.

Ruminal bacteria can use various sources of N (primarily ammonia and some amino acids and peptides), energy (derived from fermentation) and minerals for growth. The supply of ammonia can be inadequate when either the intake of protein or the ruminal degradation of protein is low. The minimum concentration of ammonia-nitrogen in ruminal fluid needed for bacterial growth and digestion has been estimated by various procedures. Concentrations above 5 mg ammonia-nitrogen per 100 ml of rumen fluid generally appear to be adequate.

Ammonia is derived from degradation of protein or non-protein nitrogen (NPN) in the rumen. Although most bacterial species in the rumen can survive using ammonia as their sole source of nitrogen (5), added protein may stimulate bacterial growth. Typically, the least costly dietary source of rumial ammonia is some form of NPN.

Non-Protein Nitrogen

The NPN source most commonly fed to cattle is urea. Proper management procedures are necessary when NPN is fed both to prevent ammonia toxicity and to avoid reduction in feed intake. Urea is rapidly hydrolyzed to ammonia in the rumen and excessive amounts of absorbed ammonia can prove toxic to cattle. Single doses of urea at .3 to .8 g of urea per kg of body weight are toxic. Toxicity can be avoided by thoroughly mixing urea with the diet and setting maximum concentration at 1% of the diet dry matter or one-third of the total protein in the diet. With typical diets for beef cattle, 1% urea usually exceeds the amount needed to meet the microbial requirements. Levels above .6% may reduce feed intake, so lower levels may be desirable. Incorporating urea or NPN into silages has helped reduce feed intake problems with higher NPN levels. Slowly degraded sources of NPN help avoid ammonia intoxication, but ruminal bacteria appear to use urea as well as ammonia from "slow release" compounds.

Urea is used more completely when high energy and low protein diets are fed. High concentrate diets will provide more energy for synthesis of bacterial protein from ammonia. Such diets also will reduce ruminal pH which decreases the rate of ammonia absorption from the rumen and likelihood of urea (really ammonia) toxicity (4). When NPN is sustituted for protein in a diet, sulfur, phosphorus and potassium may need to be added since these minerals are usually provided by protein souces but are absent from NPN sources.

The amount of NPN which can be usefully added to a diet depends on the relative amounts of 1) protein degraded to ammonia in the rumen and 2) bacterial protein synthesis. Bacterial protein synthesis in turn usually depends on the amount of energy available in the rumen. These limits have been calculated by Burroughs *et al.* (6) and can be combined to predict the need for urea in diets with different levels of protein degradation as illustrated in table 7.

Unfortunately, ruminal degradation of dietary protein is difficult to predict. Further, roughage level, feed intake level and feed processing influence both degradation of protein in the rumen and energy supply for and efficiency of bacterial growth. So these equations should be modified for specific feeding and management conditions. Several systems have evolved in the past decade which can be used to estimate urea usefulness, protein bypass and postruminal requirements for cattle. The reader is referred to reviews and symposia for information on these systems (37, 39).

Ruminal Protein Degradation and Bypass

Dietary protein is digested in the rumen to a variable degree depending on feed, ruminal, animal and time conditions. The balance of the dietary protein which escapes destruction in the rumen and passes to the omasum and

TABLE 7. Urea usefulness based on dietary energy, ruminal protein degradation, and protein requirements.

Protein Needed %	Ruminal protein degradation, %	TDN, % of Dry Matter 55	60	65	70	75	80	85
		Urea which can be added, % of Dry Matter						
8	30	0.71	0.79	0.87	0.97	1.07	1.18	1.31
8	50	0.42	0.51	0.61	0.72	0.83	0.96	1.10
8	70	0.05	0.15	0.27	0.39	0.52	0.67	0.83
9	30	0.65	0.73	0.81	0.91	1.01	1.12	1.25
9	50	0.31	0.39	0.49	0.60	0.72	0.84	0.98
9	70	—0.14	—0.04	0.07	0.20	0.33	0.48	0.64
10	30	0.58	0.66	0.75	0.84	0.95	1.06	1.18
10	50	0.19	0.28	0.37	0.48	0.60	0.72	0.87
10	70	—0.33	—0.23	—0.12	0.00	0.14	0.29	0.45
11	30	0.52	0.60	0.69	0.78	0.88	1.00	1.12
11	50	0.07	0.16	0.25	0.36	0.48	0.61	0.75
11	70	—0.53	—0.42	—0.31	—0.19	—0.05	0.10	0.26
12	30	0.46	0.54	0.62	0.72	0.82	0.93	1.06
12	50	—0.05	0.04	0.13	0.24	0.36	0.49	0.63
12	70	—0.72	—0.62	—0.50	—0.38	—0.24	—0.10	0.07
13	30	0.40	0.47	0.56	0.65	0.76	0.87	0.99
13	50	—0.17	—0.08	0.02	0.12	0.24	0.37	0.51
13	70	—0.91	—0.81	—0.70	—0.57	—0.44	—0.29	—0.13

A negative value implies that urea addition is useless.

abomasum is commonly called "bypass" or "escape" protein. Protein escaping or bypassing ruminal destruction is either digested postruminally or, if indigestible, is excreted in feces. Since the extent of ruminal degradation of dietary protein depends on bacterial, animal and time conditions in addition to chemical and physical properties inherent to the protein, "degradability" varies with feeding and animal parameters.

In the rumen, most protein which is soluble in ruminal fluid plus a variable proportion of the insoluble protein is degraded to ammonia (7, 24). But solubility alone is a poor index of the extent of degradation (48) except possibly with high intakes of a high concentrate diet. Protein from various feedstuffs has been classified into three relative ruminal bypass or escape categories (1, 7, 48) as presented in table 8.

TABLE 8. Bypass or Escape of Protein from Various Sources.

Category	Protein sources
Low bypass (less than 40%)	Soybean meal, Peanut meal
Medium bypass (40 to 60%)	Cottonseed meal, Dehydrated alfalfa meal, Corn grain, Brewers dried grains
High bypass (over 60%)	Meat meal, Corn gluten meal, Blood meal, Feather meal, Fish meal.

These estimates do not consider feed processing conditions or animal, dietary and microbial variables which can markedly alter bypass, especially for the more rapidly degraded protein sources (59). These factors act through modifying 1) ruminal retention time for digestion and 2) microbial activity within the rumen. When these factors are more fully quantitated and the postruminal need for protein is more precisely described, specific bypass estimates for various feedstuffs will become useful.

Amount of each amino acid, not total protein, is the primary factor of interest in protein nutrition. Certain amino acids of protein may be bypassed less than others, so that amino acid composition of escape protein may differ from that of fed protein (31) though changes with some protein sources such as soybean meal appear to be minor (55).

When high bypass protein is fed, the amount of NPN needed in the diet will increase since less dietary protein is degraded to ammonia in the rumen. Increased bypass or escape does not ensure that animal production will increase. This is because 1) bypassed protein can be (and often is) poorly digested in the small intestine, 2) the balance of amino acids in postruminal protein can be poor and 3) nutrients other than amino acids may limit animal production. Protein demands are highest for lactation and very rapid growth rates.

Protein is often fed at levels in excess of the absolute requirements of growing cattle due to the low marginal cost of protein. In contrast, feeding protein in excess of requirements is infrequent with lactating beef cows, which obtain their other nutrients from grazed forage. The economic sacrifices in performance and reproduction and the potential for use and replinishment of protein reserves must be balanced against the cost of feeding protein to cattle to determine the most economical level of supplementation.

Requirements on the basis of percentage in the diet have been calculated from feed intake. Amounts per day rather

than percentage requirements should be employed when feed intakes deviate from listed values. Certain additional factors such as heat, cold or shipment stress, diet processing, feed additives, estrogenic implants and previous protein and energy intake may alter feed intake, rate of weight gain and composition of tissue gain. Adjustments for the effects of these factors on feed intake and rate of protein deposition have been discussed in an NRC publication (35) but are not well quantitated.

Protein Deficiencies and Toxicities

Ammonia deficiency in the rumen reduces the rate and extent of digestion and may reduce feed intake. Postruminal amino acid deficiencies also may reduce energy intake and efficiency of feed and protein use. Through recycling nitrogen to the rumen, efficiency of protein use is greatest with a marginal protein deficiency. Requirements for protein listed in tables 2, 6, 10 and 11 may be inadequate for certain diets and feeding conditions. When protein comprises less than 10% of dietary dry matter, ammonia may be insufficient for ruminal microbes. The amount of ammonia needed for ruminal microbes can be calculated from the "urea potential" equations listed previously.

Change in feed intake may be useful as an indicator of protein deficiency. If intake of feed increases when protein is added to the diet, protein was probably deficient, while if intake does not increase, protein probably was not a limiting factor. Diets containing up to 40% protein have been fed to steers. Feed intake was reduced for several days when protein was added, but no signs of ammonia toxicity were evident (15). Excesses of NPN or soluble protein may precipitate ammonia toxicity as discussed earlier.

Protein Requirements of Cattle

Greater value for protein sources which largely escape ruminal destruction ("high bypass" proteins) such as distillers products, corn gluten, meat meal and blood meal relative to more conventional protein sources such as soybean meal and cottonseed meal has been demonstrated in laboratory studies and in certain feeding trials with growing calves limit fed low protein diets (27). Increased protein bypass also appears useful for increasing mobilization of body energy reserves for high levels of lactation (36). Differences in amino acid composition (especially available lysine) may be important for comparison within these "high bypass" protein supplements. Benefit to increased bypass is not observed under all production or maintenance conditions. With wintered range cows, feather meal (30) and blood meal (42) have proven inferior to soybean meal in supplements, even though protein bypass should be greater with feather and blood meals. An increased postruminal protein supply also failed to increase feed intake or nitrogen balance of growing steers fed a high concentrate urea supplemented corn diet free choice (25).

The need for protein can be factored into specific metabolic functions or losses. These include metabolic fecal loss (F), endogenous urinary loss (U), scurf loss (S), deposited body or fetal tissue (T) and milk production (M). One such factorial equation is: $CP=(F + U + S + T + M)/(CE \times D \times BV)$ where CE is conversion efficiency in the rumen (nitrogen output to the omasum divided by nitrogen intake from feed), D is true digestibility, and BV is biological value or efficiency of utilization of absorbed N.

The components of this equation have been partially described in the Dairy NRC (34) bulletin. Metabolic fecal protein loss (F) for ruminants in grams per day appears to be a function of dry matter intake or fecal dry matter excretion as illustrated in table 1. The current estimate of F is 3 percent of dry matter intake or 6.8 percent of fecal dry matter. Regression of a series of steer trials yielded a value of 3.34% of dry matter intake. Replacement of F is the major protein cost for ruminants under most conditions (table 9). To calculate F, dry matter output in feces or input in feed needs to be estimated. Unfortunately, feed intake cannot be predicted well as reviewed by Owens and Gill (38). Besides being influenced by energy content of the diet, intake will vary with feed characteristics, various animal factors and feeding methods. Intakes for this paper have been estimated based on averages of current equations.

Endogenous urinary loss, (U), in grams per day, estimated from protein-free rations, can be calculated from body weight in kg (W) as: $U = 2.75\ W.5$. This loss should include nucleic acids synthesized by ruminal microorganisms. Scurf (S) loss (skin, hair, horn and hoof) in grams per day is estimated from surface area as $S = 0.2\ W.6$ (34).

Tissue protein deposition (T) in grams per day has been estimated by several workers using comparitive slaughter techniques and deuterium dilution procedures. Composition of gain depends upon physiological maturity of the animal and rate of weight gain. Protein deposition rates have been summarized in several different equations and usually have been calculated relative to weight (W) in kilograms and daily gain (ADG) in kilograms. Though T differs at extreme rates of gain and with very light and heavy weight cattle depending on which equation is used, T for typical animals (a 500 pound steer gaining 2 pounds per day) agree to some extent (137 to 160 g/day, respectively).

Though rate of protein deposition can be related by equations to rate of gain and animal type, relating protein deposition to energy content of gain seems more logical since this permits integration with the net energy system for various types of cattle. Protein deposition then becomes the multiple of rate of weight gain and chemical composition of the gain. Protein deposition calculated from all four equations were averaged and regressed against energy content of weight gained (ECG, in mcal/kg) calculated from the net energy equation. This generated the equation: Protein deposition (T) = ADG (268 - 29.4 ECG). Energy content of gain in turn is calculated as daily NE_g intake divided by weight gain. Rate of deposition of protein should be similar for cattle of equivalent size as described by Fox et

TABLE 9. Influence of weight gain on protein need of a 500 pound large frame steer.

	Daily Gain lb.						
	.5	1.0	1.5	2.0	2.5	3.0	3.5
Feed intake, lb.	12.0	12.8	13.4	13.8	14.0	14.0	13.6
Diet TDN, %	52.5	56.0	59.5	63.5	67.5	72.0	78.5
Protein uses, g/day							
F = Metabolic fecal	181	194	204	208	212	213	206
U = End. urinary	41	41	41	41	41	41	41
S = Scurf	5	5	5	5	5	5	5
T = Tissue	46	86	127	167	207	247	285
CE*D*BV, value	.59	.59	.59	.59	.59	.59	.59
Total protein need,							
lbs./day	1.01	1.21	1.40	1.56	1.73	1.88	2.00
Percent of DM	8.5	9.5	10.4	11.4	12.4	13.4	14.7

al. (17). Nitrogen retention is the sum of T and S.

Next, to convert the body's needs enumerated above to a dietary requirement, the efficiency of converting dietary protein to absorbable or metabolizable protein must be considered. This is the multiple of three factors: ruminal conversion efficiency (CE), true digestibility (D) and biological value (BV) of the absorbed amino acids.

Efficiency of converting fed protein or nitrogen to non-ammonia nitrogen (primarily protein) leaving the rumen (CE) is the center of controversy. Ruminal output divided by protein intake may exceed 1.0 when high bypass proteins are fed or with low protein diets where nitrogen recycled to the rumen is used by ruminal microbes. In contrast, when ruminal degradation of protein is high or the amount of NPN exceeds the amount usable by bacteria, ruminal protein output will be less than feed protein input making CE<1. Since ruminal output is the sum of microbial protein and bypassed protein, values for these two components are needed. Microbial protein passage is the multiple of 1) organic matter digested in the rumen and 2) efficiency of microbial growth. These factors both exhibit variations of 30% or more. Bypass is dependent on feed composition, additives and processing conditions, as well as animal, dietary and microbial variables. These modify bypass, especially for more degradable proteins. These modify bypass, especially for more degradable proteins, through altering 1) bacterial activity in the rumen and 2) ruminal retention of specific protein fractions of a feedstuff. How these factors change both microbial protein synthesis and bypass needs further study before ruminal output can be precisely described. Averaged over 11 experiments (58), ruminal output of non-ammonia nitrogen was .96 multiplied by nitrogen intake with diets that averaged 15.6 percent protein. A CE of 1.0 was used for these calculations, though this value should reflect specific dietary or animal conditions.

True protein digestibility (D) and biological value (BV) also will vary among feedstuffs and dietary conditions. Small intestinal digestibility of non-ammonia nitrogen from feed plus microbial protein has averaged 66 percent (58), but true digestibility in the total tract is near 90 percent (50). For amino acids and tissue needs, the lower figure may be appropriate. But when estimating nitrogen needed to replace factored use of nitrogen with metabolic fecal loss included as a requirement, the higher figure must be employed. When a sizeable portion of the protein of a ration is bound to fiber or is indigestible by pepsin, this digestibility figure should be correspondingly reduced.

Biological value (BV) is an index of the level of the most limiting amino acid in a protein. BV of microbial crude protein, estimated from studies with non-ruminants, ranges from 66 to 81 percent. The high nucleic acid content of the crude protein of microbial cells is partly responsible for this low BV. Abomasal supplementation with certain amino acids (lysine, threonine and amino acids containing sulfur) has increased the BV of microbial protein for steers (7). The BV of the total protein reaching the small intestine must be considered, not just the BV of supplemental bypass protein. Since amino acid composition of protein used for different functions will vary, postruminal protein may have a different BV depending on its destination as described by the Dairy NRC committee. This parallels subdivision of net energy with different efficiencies for maintenance versus growth. But with amino acids being drawn from a common pool for all functions, subdividing BV's for various metabolic functions does not appear appropriate.

To check the overall efficiency of use (the multiple of CE, D and BV) of consumed N, protein intake of protein deficient cattle from 73 trials in the recent literature were regressed on calculated use of protein (F, U, S, and T). In trials where added protein increased rate of gain, protein was considered to be deficient. Since gain was limited by protein supply, efficiency of protein use should be maximized. Calculations revealed a mean efficiency of dietary N use of 60 percent. If CE is 1.0 and D is 0.9, then BV would be .66 from these 73 trials.

Factorially calculated protein requirements are presented in the tables attached. To achieve more rapid gains (table 9), energy intake must increase. Energy intake can be increased by elevating the energy density of the diet or by increasing feed intake. But feed intake is limited at low energy density by bulk factors and at high energy density by metabolic factors. As rate of gain increases, protein deposition will increase, fecal loss (F) will increase to a plateau, and total

pounds of protein needed will increase. Protein need divided by feed intake yields requirement as a percent of the diet. This percentage increases but not as drastically as the pounds of protein needed.

Requirements for protein for various classes gaining at a given rate can be calculated in a similar manner (table 10). This reveals surprisingly little difference in the protein percentage needed in diets for these classes. But note that these gains are obtained with different energy densities. If all classes were fed the same diet, large frame steers and bulls would eat more feed and gain from .5 to 1 pound more each day than heifers of similar weight, and this would lead to a greater requirement for protein. With maturity, feed intake increases (table 11) causing F to increase, but T drops. Consequently, protein requirements expressed as a percent of feed dry matter decrease. Whether microbial action in the rumen and feed intake would be reduced with these lower protein levels (calculated to meet the body demands for protein) remains open to question. Assuming these diets are composed of typical feedstuffs, the diets would have urea fermentation potentials of 0 to 8 indicating that urea could be usefully added to increase protein levels by 0 to 2.2 percentage units. More research is needed to define and test the benefit of supplemental urea for heavier weight cattle. Maintenance requirements from Smutz (49) match with U loss calculated from these equations reasonably well, but note that F and S are not included in the Smutz estimation of protein needs for maintenance. Overall, these tables illustrate that energy density (which influences rate of gain), class of cattle and weight of cattle will alter the need for protein. Ideally, cattle should be sorted into similar groups for feeding, and protein percentage should be reduced as cattle grow.

From the 73 trials mentioned above, the use of protein was compared to estimated requirements. The mean value was very close, as might be expected since these data were used to calculate the constants in the equation. But the standard deviation from the estimated requirement was 14 percent. This means that for a diet to be adequate for cattle in 84 percent (not just 50 percent) of these trials, the estimated requirement should be multiplied by 1.14. Such an adjustment has not been made in the attached tables. The value of this safety factor needs to be compared with the cost of additional protein. Typically, the difference in cost of energy and protein feedstuffs is small enough to make some safety margin economical, especially if .1 pound of dietary protein deficiency reduces tissue protein gain by .167 pounds (1/.59) and rate of gain by .9 pounds. **Feedstuffs (protein content, pepsin digestibility, solubility) and animal types need to be described more fully in reports of research in the future to permit greater refinement of factorialized protein requirements.**

TABLE 10. Intake, protein losses and needs for various classes of 500 pound cattle gaining 2 pounds per day.

Sex Frame or age	Steer calf	Steer yearling	Bull Large	Heifer Large
Feed intake	13.1	13.8	13.2	13.1
Diet, % TDN	67.5	63.5	62.5	69.5
Protein use (g/day)				
F = Fecal	199	208	203	198
U = Urinary	41	41	41	41
S = Scurf	5	5	5	5
T = Tissue	158	167	176	150
CE*D*BV, value	.59	.59	.59	.59
Dietary need for protein				
Pounds/day	1.49	1.57	1.58	1.46
Percent	11.4	11.4	11.8	11.2

References

1. Agricultural Research Council. 1980. Nutrient Requirements for Ruminant Animals. Agricultural Research Bureaux, Great Britain. 2. Anonymous. 1983. Feed Additive Compendium. Miller Publishing Co., St.

TABLE 11. Protein expenditures and estimated requirements of large framed steers of different weights gaining 2 pounds per day.

	Steer weight						
	400	500	600	700	800	900	1000
Feed intake, lb.	11.7	13.8	15.8	17.8	19.6	21.4	23.2
Protein needs (g)							
F= Fecal	176	208	239	268	297	324	351
U = Urinary	37	41	45	49	52	56	59
S = Scurf	5	5	6	6	7	7	8
T = Tissue	179	167	156	144	135	125	116
CE*D*BV, val.	.59	.59	.59	.59	.59	.59	.59
Dietary protein need							
Pounds/day	1.47	1.57	1.66	1.74	1.82	1.90	1.98
Percent	12.7	11.4	10.5	9.8	9.3	8.9	8.6
Urea fermentation potential							
g urea/kg feed	0	2	4	5	6	7	8
Maintenance requirement (g/day)							
Smutz (1935)	40	47	54	60	66	72	78
U = Urinary	37	41	45	49	52	56	59

Paul, MN. 3. Bartley, E. E. 1976. Bovine saliva: Production and function. In: M. S. Weinberg and A. L. Sheffner (Eds.) Buffers in Ruminant Physiology and Metabolism. pp. 61. Church and Dwight Co., Inc., Nutley, New Jersey. 4. Bartley, E. E., A. Davidovich, G. W. Barr, G. W. Griffel, A. D. Dayton, C. W. Deyoe and R. M. Bechtle. 1976. Ammonia toxicity in cattle. I. Rumen and blood changes associated with toxicity and treatment methods. J. Anim. Sci. 43:835. 5. Bryant, M. P. and I. M. Robinson. 1963. Apparent incorporation of ammonia and amino acid carbon during growth of selected species of ruminal bacteria. J. Dairy Sci. 46:150. 6. Burroughs, W., D. K. Nelson and D. R. Mertens. 1975. Protein physiology and its application in the lactating cow: The metabolizable protein feeding standard. J. Anim. Sci. 41:933. 7. Chalupa, W. 1975. Rumen bypass and protection of proteins and amino acids. J. Dairy Sci. 58:1198. 8. Counotte, G. H. M., A. Th. van't Klooster, J. van der Kuilen and R. A. Prins. 1979. An analysis of the buffer system in the rumen of dairy cattle. J. Anim. Sci. 49:1536. 9. Dawson, K. A. and J. A. Boling. 1983. Effects of sodium and potassium ion concentrations on the antimicrobial activities of ionophores against rumen anaerobes. XVII Rumen Function Conference, Chicago. 10. DeHaan, K. A., T. J. Klopfenstein, O. A. Turgeon, R. A. Britton and D. R. Brink. 1982. Effect of buffers on fiber digestion in vivo. J. Anim. Sci. 55 (Supp. 1):416. 11. Elanco, 1975. Rumensin Technical Manual. Elanco Products Co., Indianapolis, IN. 12. Emery, R. S. 1976. High energy feeds for milk production. In: M. S. Weinberg and A. L. Sheffner (Eds.) Buffers in Ruminant Physiology and Metabolism. pp. 149. Church and Dwight Co., Inc., Nutley, New Jersey. 13. Erdman, R. A., R. W. Hemken and L. S. Bull. 1982. Dietary sodium bicarbonate and magnesium oxide for early postpartum lactating dairy cows: Effects on production, acid base metabolism and digestion. J. Dairy Sci. 65:712. 14. Erfle, J. D., R. J. Boila, S. Mahadevan, R. Teather and F. D Sauer. 1981. The effect of pH on the fermentation of mixed rumen bacteria in continuous culture. J. Dairy Sci. 64(Supp. 1):138. 15. Fenderson, C. L. and W. G. Bergen. 1976. Effect of excess dietary protein on feed intake and nitrogen metabolism in steers. J. Anim. Sci. 42:1323. 16. Ferreira, J. J., C. H. Noller, R. B. Keyser and J. L. White. 1979. Particle size and reactivity of feed grade limestone. J. Anim. Sci. 49(Supp. 1):367. 17. Fox, D. G., C. G. Sniffen and P. J. Van Soest. 1982. A net protein system for cattle: Meeting protein requirements of cattle. In. Protein Requirements for Cattle, Symposium. Ok. State Univ. Misc. Publ. MP-109:280. 18. Franklin, K. K., J. E. Winch and G. K. MacLeod. 1981. The effect of concentrate on the digestion of bromegrass constituents. Can. J. Anim. Sci. 61:935. 19. Ganev, G., E. R. Orskov and R. Smart. 1979. The effect of roughage or concentrate feeding and rumen retention time on total degradation of protein in the rumen. J. Agric. Sci. (Camb.) 93:651. 20. Haaland, G. L. and H. F. Tyrrell. 1982. Effects of limestone and sodium bicarbonate buffers on rumen measurements and rate of passage in cattle. J. Anim. Sci. 55:935. 21. Haaland, G. L., H. F. Tyrrell, P. W. Moe and W. E. Wheeler. 1982. Effect of crude protein level and limestone buffer in diets fed at two levels of intake on rumen pH, ammonia-nitrogen, buffering capacity and volatile fatty acid concentrations of cattle. J. Anim. Sci. 55:943. 22. Hale, W. H. and P. Meinhart (Eds.) Regulation of Acid-Base Balance. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., Nutley, New Jersey. 23. Hart, S. P. and C. E. Polan. 1982. Effect of sodium bicarbonate and disodium phosphate on rate of passage of liquid and particulate digesta. J. Anim. Sci. 55(Supp. 1):427. 24. Henderickx, H. and J. Martin. 1963. In vitro study of the nitrogen metabolism in the rumen. Comptes Rendes de Recherches. Sci. Ind. Agr. Bruxelles 31:1. 25. Johnson, A. B., F. N. Owens and K. L. Mizwicki. 1982. Abomasal protein infusion for growing steers fed corn grain rations. J. Anim. Sci. 54:189. 26. Kincaid, C. R., W. H. Hoover and L. L. Junkins. 1981. The effect of pH and dilution rate on rumen fermentation in continuous culture. J. Anim. Sci. 53(Supp. 1):411. 27. Klopfenstein, T., R. Britton and R. Stock. 1982. Nebraska growth system. In. Protein Requirements for Cattle, Symposium. Ok. State Univ. Misc. Publ. MP-109:310. 28. Kronfeld, D. S. 1979. Sodium, osmolarity and hydration. In: W. H. Hale and P. Meinhardt (Eds.) Buffers in Ruminant Physiology and Metabolism. pp. 11. Church and Dwight Co., Inc., Nutley, New Jersey. 29. Laudert, S. B. and J. K. Matsushima. 1982. Limestone effects on digestion and gastrointestinal tract pH of finishing steers. J. Anim. Sci. 55(Supp. 1):437. 30. Leme, P. O. Forero, F. N. Owens and K. S. Lusby. 1978. Feather meal as a protein source for range cows. Ok State Univ. MP-103:31. 31. Macgregor, C. A., C. J. Sniffen and W. H. Hoover. 1978. Amino acid profiles of total and soluble protein in feedstuffs commonly fed to ruminants. J. Dairy Sci. 61:566. 32. Muller. L. D. and L. H. Kilmer. 1979. Sodium Bicarbonate in Dairy Nutrition. Church and Dwight Co., Inc., Nutley, New Jersey. 33. Mertens, D. R. 1979. Effects of buffers upon fiber digestion. In: W. H. Hale and P. Meinhardt (Eds.) Regulation of Acid-Base Balance. p. 65. Church and Dwight Co., Inc. Nutley, New Jersey. 34. National Research Council. 1978. Nutrient Requirements of Domestic Animals, No. 3. Nutrient Requirements of Dairy Cattle. NAS-NRC, Washington, D.C. 35. National Research Council. 1981. Effects of Environment on Nutrient Requirements of Domestic Animals. National Academy Press, Washington, D.C. 36. Orskov. E.R., D. A. Grubb and R. N. B. Kay. 1977. Effect of postruminal glucose of protein supplementation on milk yield and composition in Friesian cows in early lactation and negative energy balance. Brit. J. Nutr. 38:397. 37. Owens, F. N. (Ed.). 1982. Protein Requirements for Cattle: Symposium. Okla. State Univ. MP-109. 38. Owens, F. N. and D. R. Gill. 1982. Influence of feed intake on site and extent of digestion. Proc. Distillers Feed Conference 37:41. 39. Owens, F. N. and W. G. Bergen. 1983. Nitrogen metabolism of ruminant animals: Historical perspective, current understanding and future implications. J. Anim. Sci. 57(Supp. 2):498. 40. Owens, F. N., D. C. Weakley, A. L. Goetsch and R. A. Zinn. 1983. Buffers in feedlot diets. In: Buffers, Neutralizers and Electolytes in Livestock Diets. National Feed Ingredients Association, Des Moines. 41. Owens, F. N. and R. A. Zinn. 1982. Calcium nutrition and buffers for feedlot cattle . Proc. Am. Feed. Mfg. Assn. p. 42. Peterson, M. K., D. C. Clanton, T. Klopfenstein, G. W. Walker and M. E. England. 1981. Abomasal nitrogen flow, nitrogen balance and dry matter as influenced by nitrogen source in range supplements. J. Anim. Sci. 53(Supp. 1):117. 43. Rogers, J. A. and C. L. Davis. 1982a. Rumen volatile fatty acid production and nutrient utilization in steers fed a diet supplemented with sodium bicarbonate and monensin. J. Diary Sci. 65:944. 44. Rogers. J. A. and C. L. Davis. 1982b. Effects of intraruminal infusions of mineral salts on volatile fatty acid production in steers fed high-grain and high-roughage diets. J. Dairy Sci. 65:953. 45. Rogers. J. A., B. C. Marks, C. L. Davis and J. H. Clark. 1979. Alteration of rumen fermentation in steers by increasing rumen fluid dilution rate with mineral salts. J. Dairy Sci. 62:1599. 46. Rust, S. R. and F. N. Owen. 1982. Effect of limestone on digestibility of feedlot diets. Ok. Ag. Expt. Sta. Misc. Pub. 112:154. 47. Satter, L. D. and R. E. Roffler. 1975. Nitrogen requirements and utilization in dairy cattle. J. Dairy Sci. 58:1219. 48. Satter, L. D., L. W. Whitlow and G. L. Beardsley. 1977. Resistance of protein to rumen degradation and its significance to the diary cow. Distillers Feed Research Council Proc. 32:63. 49. Smutz, B. B. 1935. The relationship between the basal metabolism and the endogenous nitrogen metabolism with particular reference to the maintenance requirement of protein. J. Nutr. 9:403. 50. Swanson, E. W. 1982. Estimation of metabolic protein requirements to cover unavoidable losses of endogenous nitrogen in maintenance of cattle. In. Protein Requirements for Cattle, Symposium. Ok. State Univ. Misc. Publ. MP-109:183. 51. Tagari, H, N. S. Reddy and L. D. Satter. 1982. Effect of magnesium oxide and sodium bicarbonate on the environment and digestion in the rumen and the gastrointestinal tract of lactating cows. J. Anim. Sci. 55(Supp. 1):468. 52. Tissera, G. H., J. H. Vandersall and R. A. Erdman. 1982. Gastrointestinal effects of limestone in the diet of growing steers. J. Anim. Sci. 55(Supp. 1):470. 53. Trenkle, A. H. 1979. Sodium Bicarbonate in Beef Nutrition. National Feed Ingredients Association, West Des Moines, IA. Church and Dwight Co., Inc. Nutley, New Jersey. 54. Wagner, D. 1982. Ionophore comparisons for feedlot cattle. OK Cattle Feeders Seminar, p N. 55. Weakley, D. C. 1983. Influence of roughage level, ruminal pH and ammonia concentration on ruminal protein degradation and microbial protein synthesis in cattle. Ph. D. Thesis. Okla. State Univ., Stillwater, OK 74078. 56. Weinberg, M. S. and A. L. Sheffner (Eds.) Buffers in Ruminant Physiology and Metabolism. Church and Dwight Co., Inc., Nutley, New Jersey. 57. Zinn, R. A. and F. N. Owens. 1980. Sodium, calcium and potassium salts for cattle fed high concentrate rations. OK. Ag. Expt. Sta. Misc. Pub. 107:131. 58. Zinn, R. A. and F. N. Owens. 1982. Predicting net uptake of nonammonia N from the small intestine. In. Protein Requirements for Cattle, Symposium. Ok. State Univ. Misc. Publ. MP-109:133. 59. Zinn, R. A. and F. N. Owens. 1983. Influence of feed intake level on site of digestion in steers fed a high concentrate diet. J. Anim. Sci. 56:471.