1977

Sodium Bentonite, Sodium Bicarbonate and Limestone Supplementation in High-Concentrate Diets for Ruminants

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SODIUM BENTONITE, SODIUM BICARBONATE AND LIMESTONE SUPPLEMENTATION IN HIGH-CONCENTRATE DIETS FOR RUMINANTS

by

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A thesis submitted in
partial fulfillment of the requirements
for the degree Master of Science, Major
in Animal Science, South Dakota
State University
1977

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor Date

Head, Animal Science Department Date

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation for the guidance, motivation, technical assistance and friendship offered so generously by his major advisor, Dr. R. J. Emerick, Professor of Chemistry and by Dr. L. B. Embry, Professor of Animal Science, during the preparation of this thesis and completion of his required course work.

The author would also like to thank Anna M. Baumiller for her expert job of typing the final draft of this thesis. Appreciation is extended to Dr. W. L. Tucker for his assistance in the statistical analysis of the data, the technicians at the Beef Cattle and Sheep Nutrition Unit for their help and friendship, and to Carol A. Shally for her accurate record keeping and preparation of the data for analysis.

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INTRODUCTION

In the past several years, there has been increased interest in what has been referred to by some as the two-phase feeding of ruminants. This includes backgrounding, when animals are fed diets high in roughage during a growing period, followed by high-grain feeding during a relatively short finishing period. An interim period of grain adaptation, usually 2 to 3 weeks in length, is necessary in this feeding system to avoid the deleterious effects of the rumen acidosis associated with abrupt changes from predominantly roughage diets to high-grain diets. Feedlot performance during this adaptation phase is generally lower than desired.

The feeding of low levels of alkaline materials and other inorganic mineral substances such as bentonite has shown some benefit in the past in maintaining normal gains during abbreviated adaptation periods. The objectives of the experiments reported herein were to: 1) evaluate various materials in terms of protection that they may provide from rumen acidosis associated with an abrubt change in diets, 2) to combine sodium bentonite and sodium bicarbonate to determine if there are possible synergistic actions, and 3) to determine effects of these materials on overall performance when fed to ruminants throughout the feeding period.

REVIEW OF LITERATURE

Rumen acidosis

The general health and welfare of the ruminant animal is largely dependent upon the maintenance of a homeostatic relationship between the end products of microbiological fermentation in the rumen and the animal's physiological responses to these end products. The maintenance of this steady-state is to a large degree dependent on the amount and type of ingested substrate, salivary production, rumination, rumen motility, rate of passage and acid-base balance. Any change or disruption in the normal functioning of these mechanisms could lead to a weakened condition and/or death of the animal.

When large quantities of highly soluble carbohydrates are ingested by a ruminant that has previously been consuming a diet high in fibrous carbohydrates, disruptions of the normal digestive mechanisms take place. The pathology that results has been the subject of much research in the last quarter century. It has been called a variety of names including rumen acidosis, D-lactic acidosis, acute acidosis, rumen grain overload, founder, rumen impactation, acute impactation and carbohydrate engorgement (Dunlop, 1972; Jensen and Mackey, 1965; Merck, 1972).

The adaptation of an animal to a diet high in soluble carbohydrates from a diet high in fiber is microbrial in nature. The total number of bacteria remains fairly constant, but the makeup of the population changes drastically (Allison *et al*., 1964; Chaplin and Jones, 1973; Hungate *et al*, 1952). Hungate *et al*. (1952) reported that during a period of adaptation to grain diets, celluloytic bacteria and protozoa disappeared completely while there was an increase in the relative number of gram-positive bacteria, particularly *Streptococcus bovis*. *S. bovis* then attacked starch and glucose molecules and produced lactic acid. In another study (Chaplin and Jones, 1973), it was found that the population of Lactobacilli increased slowly during carbohydrate engorgement and peaked at 48 hr post feeding.

The change in the microbrial population is reflected by a change in the end products of their metabolism. Volatile acids decrease in concentration and nonvolatile acids, especially lactic acid, accumulate (Chaplin and Jones, 1973; Hungate *et al*., 1952; Reid *et al*., 1957; Ryan, 1963). Normally, ruminal lactic acid is found in very small concentrations. Balch and Rowland (1957) found only traces, less than 1 mg/100 ml, of lactic acid in the rumen of dairy cattle fed a variety of diets. When the animals were fed flacked maize, however, peak concentrations ranged from 95 to 270 mg/100 ml. Others have shown that as the concentration of lactic acid increases, the pH of the rumen has been found to drop and pH values of 4.0-4.7 have not been uncommon (Chaplin and Jones, 1973; Hungate *et al*., 1952; Irwin *et al*., 1972a; Reid *et al*., 1957).

Absorption of lactic acid and its salts has been demonstrated both from the rumen and the intestines, but the quantities and proportions entering from these sites during the various stages of lactic acidosis have not been well established. Differences in rates of absorption for the two isomers are minor. However, if the isomers are absorbed across a concentration gradient, the D-isomer may be absorbed faster because initially there would be none in the blood (Dunlop, 1972).

Once lactic acid is absorbed, there are two pathways that it can follow in metabolism. The undissociated form may ionize and release a hydrogen ion. This process may deplete the body's buffering reserves as the hydrogen ion combines with a bicarbonate anion to form carbonic acid. This would decompose to water and carbon dioxide which is exhaled. If the absorbed acid is the D-isomer of lactic acid, acidosis would be more severe because of the slower utilization of this isomer. If, however, the acid is absorbed as the sodium salt, metabolism of this compound may yield bicarbonate ion which builds body buffering reserves. The sodium salt of the L-isomer is a much more effective alkalinizing agent than the D-isomer (Dunlop, 1972).

Johnson et al. (1974) reported that the pH of the rumen and rumen lactate level were positively correlated with the degree of processing the grain in the diet had undergone. These workers found that not only were the type and physical properties of the diet important in producing rumen acidosis, but the time span in which it was consumed was important also. They concluded an animal would have to consume a full day's feed in one meal to produce severe acidosis.

Some researchers have expressed the opinion that the rumen fluid of animals suffering from rumen acidosis contains substances toxic to the animal. Dougherty and Cello (1949) reported that rumen ingesta, when injected into a variety of animals, caused decreased blood pressure and increased respiration and motor activity. Some injections were fatal to dogs. They were not able to isolate any toxic substances from the rumen fluid tested. Several reports (Dain *et al.*, 1955; Irwin *et al.*, 1972a) have implicated histamine and tryamine as toxic substances in the rumen fluid of animals suffering rumen acidosis. Dain *et al.* (1955) observed histamine in large concentrations, greater than 70 ug/ml, in the rumens of animals suffering from rumen acidosis, and its production was positively correlated with the acidity of the rumen. The degree of illness of the animals was reported to vary directly with the level of histamine in the ingesta.

The physiological effects of rumen acidosis can be very severe. Rumen motility has been observed to be partially or completely suppressed (Hungate *et al.*, 1952; Vestweber *et al.*, 1974). Vestweber and Leipold (1974) found the papillae of affected rumens to be swollen, and others (Gray, 1948; Thorlacius and Lodge, 1973) reported that absorption across the rumenal epithelium was depressed. Under conditions of extreme acidosis, necrosis of the epithelium appeared to enable bacteria, especially *Spherophorus necrophorus*, to enter veins and to be conveyed to the liver where abscesses often formed in surviving animals (Jensen and Mackey, 1965).

The generalized acidosis due to the absorption of lactic acid into the blood causes the animal to increase its respiration rate and to excrete hydrogen ions through the urine (Irwin *et al.*, 1972b; Uhart and Carrol, 1967). The kidneys of animals suffering from rumen acidosis often show degeneration of the tubules and medullary congestion (Vestweber and Leipold, 1974).

Clinical signs of rumen acidosis are exhibited quickly. Loss of appetite and central nervous system depression have generally been the first signs observed (Jensen and Mackey, 1965; Uhart and Carrol, 1967; Vestweber et al., 1974). Bhattacharya and Warner (1967) reported that depression in feed intake was due to low ruminal pH. Several researchers (Jensen and Mackey, 1965; Vestweber et al., 1974) have reported that animals suffering from this condition exhibit increased heart and respiration rates. The feces become gray and mucoid, and extreme diarrhea has been exhibited (Jensen and Mackey, 1965; Vestweber et al., 1974).

In the terminal stages, Jensen and Mackey (1965) report that the aflicted animal becomes extremely weak and quickly develops prostration, coma, subnormal body temperature and low blood pressure. Death usually occurs in 1 to 3 days. Vestweber et al. (1974) observed a 31% death loss in lambs, 5 out of 16, due to rumen acidosis. However, pregnant ewes suffered no abortions, congenital abnormalities or retained placentas. Non-fatal cases have often developed acute laminitis (Jensen and Mackey, 1965).

Bentonite in animal nutrition.

Bentonite is a rock composed of a cystalline, clay-like mineral derived from the weathering of volcanic ash (Pettijohn, 1975). It has been estimated that bentonite is composed of 90% montmorillonite. As a result, the physical and chemical properties of bentonite are largely those of montmorillonite (Iler, 1955).

Structurally, montmorillonite resembles a sandwich. The basic layer consists of pairs of siloxane sheets with each silicon atom in tetrahedral coordination with oxygen. The sheets are held together by a layer of aluminum ions which are in octahedral coordination with the oxygens of the siloxane sheets (Iler, 1955). The empirical chemical formula is: $(OH)_4\ (Al_{3.34}, Mg_{0.66})\ Si_8\ O_{20}$ (Millot, 1970).

Montmorillonite resembles mica, but bond strength between subunits is weaker (Pettijohn, 1975). This structural weakness is due to the fact that subunits are held together by water and cations, the most common cations being Na^{+1} and Ca^{+2}. The subunits range in width from 9.6 to 21.4 angstrom units (Millot, 1970; Pettijohn, 1975).

Iler (1955) has described the cation exchange characteristics of bentonite as being due to the substitution of Al^{+3} for Si^{+4} in the tetrahedral layer and Mg^{+2} for Al^{+3} in the octahedral sheet. These substitutions place an overall negative charge on the three layered subunits. This charge is balanced with the exchangeable cations and water.

Bentonite is also well known for its ability to swell as water enters the layers between subunits. When Na^{+1} is the major cation, the bonds between subunits are weak and swelling occurs readily. If Ca^{+2} is the major cation, inter-subunit bond strength is greater and uptake of water is limited (Iler, 1955).

Due to its physical properties, bentonite has been used extensively as a binder in the pelleting of feeds. Its widespread use in this capacity has created interest in its possible effect on animal performance with regard to feed intake, weight gain and feed efficiency.

Briggs and Spivey Fox (1954) observed vitamin A deficiency symptoms when 3% or more bentonite was added to synthetic diets fed to chicks. In a second experiment, with 5% bentonite incorporated into a practical diet, the chicks studied showed no detrimental effects. Laughland and Phillips (1956) reported very similar results. However, in their work, bentonite decreased the availability of vitamin A in synthetic diets, but when incorporated into practical diets no problems were observed. Blakely et al. (1955) found that 1, 2 and 5% bentonite depressed weight gains in turkey poults only when the diet was initially deficient in vitamin A.

There has been some evidence that bentonite may stimulate growth and improve feed efficiency in poultry. Kurnick and Reid (1960) reported positive results from four separate experiments. White leghorn cockerels receiving one of three energy levels (1694, 1914 and 2134 cal./kg) were fed 2.5% of their diet as sodium bentonite. Bentonite significantly increased the feed consumption and growth rate of birds receiving the lowest energy level. Bentonite showed no effect on performance with the higher energy levels. Similar results were obtained when broilers were fed these levels of bentonite and energy. The improvements observed appeared to involve improved energy and protein utilization. These researchers hypothesized that bentonite slowed the passage of feed through the gastro-intestinal tract, allowing greater utilization.

The addition of bentonite to the diets of laying hens may also have beneficial effects. Quisenberry and Bradley (1964) reported that the addition of 2.5 and 5% sodium bentonite to the diets of laying hens significantly increased egg size and improved feed efficiency. Waste materials were easier to handle as bentonite significantly reduced the amount of water in the droppings.

There has been interest in feeding low levels of bentonite to dairy cows receiving diets which depress the percentage of fat in milk. Bringe and Schultz (1969) added 5% sodium bentonite to a pelleted high-concentrate diet. The fat content of milk from cows receiving the supplementation was 30% higher than milk from cows receiving the pelleted concentrate alone. Rindsig et al. (1969) found a highly significant increase in milk fat percent when both 5 and 10% bentonite was added to a fat-depressing diet.

The long term effects of feeding sodium bentonite were studied by Slanina (1974). Dairy cows received 2 and 3% sodium bentonite for over a year and showed an increase not only in milk fat percentage but also total milk production.

The increase in milk fat percentage when sodium bentonite is fed has been explained on the basis of an increase in ruminal acetate and a decrease in ruminal propionate production (Bringe and Schultz, 1969; Colling et al., 1975b; Rindsig et al., 1969). Rindsig et al. (1969) observed a significant increase in arterio-venous acetate with 5 and 10% sodium bentonite supplementation. The increase in ruminal and blood acetate levels is followed by increased mammary uptake of acetate and a corresponding increase in milk fat percentage (Bringe and Schultz, 1969).

Results from feedlot trials with low levels of bentonite supplementation have not been as consistent as those reported with dairy cattle. Jordon (1953) found that feedlot lambs fed one-third of their protein supplement as bentonite were easier to keep on feed, and had slightly improved feed efficiency and a nonsignificant 9% increase in weight gain. Results from three separate feedlot trials by Bush and Jordon (1956) involving a total of 457 lambs were inconsistent. Lambs fed 45 g of bentonite per head daily had higher daily feed consumption and improved daily gains when compared to controls. Feeding the same level of bentonite in two following experiments showed no advantage for bentonite in feedlot performance.

When a 3% level of sodium bentonite was fed to steers receiving a high-concentrate diet, there were no effects on weight gain, feed efficiency, dry matter or crude fiber digestibility, or hepatic vitamin A retention (Erwin et al., 1957). Slanina et al. (1973b) observed that 2% bentonite in the diets of beef cattle increased weight gain while 3% bentonite lowered weight gains.

The feeding of bentonite appears to help feeder cattle and lambs get on feed faster. This advantage has resulted in better feedlot performance for the first several weeks, but it has not generally been maintained throughout the entire feeding period (Burkitt, 1969; Huntington et al., 1977b; Schake and Garner, 1976).

With such variable results it has been hard to postulate how bentonite may affect intra-ruminal metabolism and digestion. Slanina et al. (1973a) found no influence of low levels of bentonite on appetite, rumination or passage of ingested feed through the gastro-intestinal tract, and they found no accumulation of bentonite in the gastrointestinal tract. Colling et al. (1975b) reported no effect of bentonite on intra-ruminal pH, but Prigge *et al.* (1975) and Slanina *et al.* (1973a) have shown a slight buffering effect on rumen pH. However, increased concentrations of volatile fatty acids have been observed when bentonite was fed (Slanina, 1974; Slanina *et al.*, 1973a).

Bentonite's possible effect on nitrogen retention and utilization has been of interest to several researchers. In humic soils, montmorillonite absorbs amines as cations and slows their degradation (Sieskind, 1967). Everson and Jorgenson (1971) added 0.00, 0.25, 0.50 and 1.00% bentonite to corn silage and found that increasing the level of bentonite resulted in increases in pH and the concentration of organic acids, a decrease in the free alpha-amino nitrogen level, and increased incorporation of N^{15} urea into microbrial protein.

Work on nitrogen metabolism in animals fed bentonite has been variable. Kurnick and Reid (1960) reported that 2.5% sodium bentonite improved protein utilization in turkey poults receiving low and medium caloric diets. Martin *et al.* (1969) observed no effect of 2% bentonite on nitrogen retention in ruminants receiving a high-concentrate diet. However, when the diet was high in roughage, this level of bentonite improved nitrogen retention.

Rindsig and Schultz (1970) found a non-significant increase in nitrogen retention in dairy cows receiving a high-grain diet. Colling and Britton (1975a) reported both *in vivo* and *in vitro* results supporting the nitrogen retention hypothesis. In their work, lambs receiving sodium bentonite retained more nitrogen per unit of metabolic size, and nitrogen digestibility was improved. Sodium bentonite also lowered rumen ammonia at 2 and 4 hr. post feeding.

Alkali buffers in ruminant nutrition.

The addition of alkali buffers to the diets of ruminants has been widely used to counteract the deleterious effects of feeding high levels of soluble carbohydrates and the associated rumen acidosis. Bicarbonates of sodium and potassium have been the most widely used buffers.

The acid-base status of sheep changes while the animal is eating. A fall in blood pH during this time is associated with the increased loss of bicarbonate ion from the blood via the saliva into the rumen (Sasaki et al., 1974). Lactic acidosis may increase this loss of the body's buffering reserve. Supplemental sodium bicarbonate, administered intraruminally and intravenously, has been shown to be effective in raising the pH of the rumen and blood and alleviating the clinical signs of lactic acidosis (Prasad et al., 1973; Prasad and Reikib, 1975).

A variety of other buffering agents have proven effective in raising the pH of the rumen, blood or urine of several classes of livestock. Buffering materials that have been fed at various levels, with a variety of diets and in several combinations with sodium bicarbonate include: potassium bicarbonate, calcium carbonate, calcium hydroxide and magnessium oxide (Emery and Brown, 1961; Huber et al., 1969; Kendall et al., 1969; Prigge et al., 1975; Ralston and Patton, 1976; Thomas and Emery, 1969a; Thomas and Emery, 1969b).

Buffers have been observed to have other possible effects. Lee and Matrone (1971) fed purified diets to sheep that included 6% sodium bicarbonate and 4% potassium bicarbonate. Results indicated that sodium and potassium bicarbonates improved growth under a controlled-feeding regimen, but not on an *ad libitum* regimen. With bicarbonate supplementation, significantly greater levels of L (+) lactic acid than the D (-) isomer were produced, and a greater percentage of the total volatile fatty acid production was propionate.

Bhattacharya and Warner (1968) fed 5% sodium bicarbonate, 2.5% calcium hydroxide and 2% sodium carbonate to cattle and sheep. Results were the same for all experiments. Supplementation with buffers increased pH and volatile fatty acid levels in the rumen, and also increased consumption of feed and water. Blood volatile fatty acid concentrations were decreased. They hypothesized that the combination of low blood volatile fatty acid concentrations along with increased levels in the rumen and a high rumen pH disrupts the satiety mechanism in the animals and they consume more feed.

Hoar *et al*., (1969) studied the effect of sodium bicarbonate supplementation and calcium and phosphorus levels on urolithiasis in feedlot lambs. Diets with 0.28 and 0.55% of phosphorus without sodium bicarbonate produced urinary calculi in 8 and 85% of the lambs, respectively. When 2% sodium bicarbonate was added to the high-concentrate diet, 58% of the lambs in the 0.28% phosphorus group and 88% of those in the 0.55% phosphorus group developed urinary calculi.

Wheeler and Noller (1977) studied the pH of the gastrointestinal tract with regard to its effect on pancreatic amylase activity. They found that non-buffered all-concentrate diets produced a pH far below the 6.9 necessary for optimal activity of pancreatic amylase. Low fecal pH was associated with large amounts of starch in the feces.

The addition of ground limestone and magnesium limestone to these diets significantly increased intestinal pH and decreased starch in the feces from 32 to 9%.

There has been much interest over the years in adding buffers to high concentrate diets for dairy cows. While some reports have indicated that buffer supplementation to cows receiving this type of diet increases total milk production (Stanley et al., 1972; Thomas and Emery, 1969b), the major effect seems to be in preventing the decrease in milk fat percentage associated with low forage intake (Davis et al., 1964; Emery et al., 1964; Emery et al., 1965; Miller et al., 1965).

This effect on milk fat can be explained by an increase in the concentration of acetate in the rumen when a buffer is fed (Davis et al., 1964; Emery et al., 1965; Huber et al., 1969; Stanley et al., 1972). The increase in acetate production in the rumen is followed by increased mammary uptake of acetate when sodium bicarbonate and magnesium oxide are included in roughage-restricted diets (Emery et al., 1965).

Contrary to results with other classes of livestock, adding low levels of buffers to high-concentrate diets for dairy cows depressed feed intake (Miller et al., 1965; Thomas and Emery, 1969a). Feeding 454 g of sodium bicarbonate per head daily plus grain ad libitum, Emery et al. (1964) reported a 10 to 20% depression in feed intake. This feed intake depression may have been associated with decreased palatability for buffered diets (Stout et al., 1972). However, Thomas and Emery (1969b) reported depressed intake even when buffers were administered directly to the rumen and were not contained in the feed.

The effects of including alkali buffers in lamb finishing diets have been somewhat variable (Lancaster and Wilson, 1975; Lassiter, 1968). Kromann and Meyer (1966) fed 5 and 12% levels of sodium bicarbonate to lambs. These levels lowered feed intake and growth with the effect being more pronounced with high-roughage diets than high-concentrate diets.

One of the most beneficial effects of buffer supplementation for lambs may be in the adaptation to high concentrate rations. Sodium and potassium bicarbonate, and magnesium and calcium hydroxide fed at levels ranging from 1 to 3% of high concentrate diets have shown beneficial effects in reducing stress due to grain engorgement (Calhoun et al., 1974; Calhoun and Shelton, 1969; Shelton et al., 1969; Vajrabukku et al., 1976).

The inclusion of low levels of a wide range of buffering materials have improved the performance of early weaned calves. Sodium bicarbonate or mixtures of sodium bicarbonate with ground limestone, magnesium carbonate, potassium bicarbonate or disodium phosphate as 1 to 4% of the diet increasedthe pH of the rumen, blood and urine and also increased feed intake and growth rate of calves (Kellaway et al., 1976; Nicholson et al., 1960; Preston et al., 1962).

There does not seem to be any major effects of buffer supplementation on the intraruminal environment of feedlot cattle except for raising the pH (Nicholson and Cunningham, 1961; Nicholson et al., 1963a). However, low levels (1% of a high concentrate diet) of sodium bicarbonate were not even effective in raising the pH (Shaw and Pryor, 1972). Total acid production was not increased with levels of 1 to 10% of mixed buffers in high-concentrate diets (Nicholson et al., 1963a, Shaw and Pryor, 1972), nor did 5.7% of sodium bicarbonate have any influence on the digestibility of nitrogen and organic matter, or on nitrogen retention (Nicholson et al., 1962b).

The addition of sodium and potassium bicarbonate and ground limestone to high-corn diets for steers have produced variable results. Wise et al. (1961) reported adverse effects on feedlot performance when 4% sodium bicarbonate plus 7% potassium bicarbonate were added to diets for steers. Other work has indicated that 5 to 7% mixtures of these buffers increases feed consumption (Nicholson and Cunningham, 1961; Wise et al., 1965).

In two separate experiments (Nicholson et al., 1962b; Nicholson et al., 1963b), high levels of barley and oats were fed to feedlot cattle with supplemental ground limestone and sodium and potassium bicarbonate. Sodium bicarbonate as 3% of the diet increased feed intake but 5.7% did not. Mixtures of potassium bicarbonate, sodium bicarbonate and ground limestone had no effects on performance.

Work with sodium bicarbonate additions to wheat-based diets seems to be somewhat contradictory. Brethour and Duitsman (1973b) summarized nine trials with sodium bicarbonate in wheat diets. They reported a 3% increase in feed intake, 4% increase in weight gain and a 5.6% improvement in feed efficiency when low levels of sodium bicarbonate were fed. On the other hand, Pryor and Laws (1972) saw no advantage to feeding cattle 1% sodium bicarbonate in high wheat-based diets.

Although buffer supplementation might be expected to help animals adapt to high-concentrate diets under some conditions, Tremere *et al*. (1968) did not observe this to be true when feeding diets composed of 50% ground wheat, 15% ground oats and 15% corn. They found no advantage to 6% intraruminal infusions or 5% orally administered sodium and potassium bicarbonate in reducing the number of days the cattle were off feed due to grain engorgment.

The feeding of a 1% level of sodium bicarbonate did not effect feed intake but was observed to improve feed efficiency when cattle were fed diets high in corn silage (Danhmen *et al*., 1969). Lower levels of mixtures of sodium bicarbonate, calcium carbonate or calcium hydroxide produced variable results with this type of diet (Embry and Dye, 1970; Embry *et al*., 1968; Embry *et al*., 1969).

EXPERIMENTS 1 AND 2: SODIUM BENTONITE AND SODIUM BICARBONATE IN HIGH CONCENTRATE DIETS FOR RUMINANTS

Introduction

Animals changed from high-roughage backgrounding diets to high-concentrate finishing diets often experience digestive disorders related to rumen acidosis and make unsatisfactory weight gains for a period of 2 to 4 weeks. Sodium bentonite and sodium bicarbonate alter conditions in the rumen and may offer animals protection from some of the harmful effects of rumen acidosis. The potential benefits that may be derived from use of these materials have become increasingly important as backgrounding periods are extended and finishing periods are shortened.

The objectives of these experiments were: (1) to evaluate the effects of sodium bentonite and sodium bicarbonate on feedlot lambs and steers when they are subjected to a rapid conversion from roughage to concentrates; (2) to determine if these materials may have synergistic effects when fed in combination; and (3) to reduce the level fed or remove them completely from the diet after adaptation and measure the effects on subsequent feedlot performance, urinary calculi formation, and other feedlot parameters.

Experimental Procedure

Experiment 1.

The experiment was conducted with 256 crossbred lambs that originated from Texas. Average weight of the lambs was 32.9 kg. The feeding trial took place in late summer and early fall and lasted for

75 days. For 3 weeks prior to the beginning of the experiment, all lambs were offered alfalfa-brome hay *ad libitum*. The lambs were drenched for the control of internal parasites, vaccinated for the prevention of enterotoxemia and implanted with 12 mg of zeranol.

The lambs were randomly allotted to 32 outdoor pens on the basis of weight with four ewes and four wethers per pen. All pens were equipped with automatic waterers, were 24 m^2 in area and had 4.9 m of bunk space.

For the first 21 days of the experiment (designated phase 1), there were four dietary treatments with eight replications per treatment. The treatments were control, 2% sodium bentonite, 2% sodium bicarbonate, and 2% sodium bentonite plus 2% sodium bicarbonate. After completion of phase 1, sodium bentonite and sodium bicarbonate were withdrawn from one-half of the treated lambs and reduced to 1% of the diet for the remainder. These diets were fed during days 22 to 75 (phase 2) of the experiment.

The composition of the basal diet is presented in Table 1. A pooled sample representing all of the basal mixes prepared during the experiment was analyzed by proximate analysis and for calcium and phosphorus (Table 2). Calcium content was determined by atomic absorption spectrophotometry, and phosphorus and proximate analyses were by A.O.A.C. (1975) methods.

Sodium bentonite and sodium bicarbonate were added at the expense of the total diet. The sodium bicarbonate was generously provided by Church and Dwight Company, Incorporated, New York, N.Y. The sodium bentonite used in this study was "volclay, feed crumbles

TABLE 1. COMPOSITION OF THE BASAL DIET, EXPERIMENTS 1, 2 and 3.

Item	International Reference Number (IRN)	Quantity
Corn, yellow, grain, grnd (4)	4-02-992	84.4%
Alfalfa-brome hay, S-C mature, grnd (1)	1-00-253	8.0%
Soybean, seeds, solv-extd, grnd, mx 7% fiber (5)	5-04-604	6.0%
Limestone, grnd, mn 39% Ca (6)	6-02-632	0.8%
Potassium chloride, KCL (6)	6-03-756	0.3%
Trace mineral salt (6)		0.5%
Vitamin A, 30,000 IU/g as vitamin A palmitate (7)		1100 IU per kg
Vitamin E, 220 IU/g as *alpha*-tocopheol (7)		22 IU per kg

TABLE 2. PROXIMATE AND MINERAL ANALYSES OF BASAL DIET, DRY BASIS, EXPERIMENT 1.

Item	Percent
Ether extract	3.03
Crude fiber	5.05
Crude protein	14.36
Ash	4.23
Nitrogen-free extract	73.33
Calcium	0.52
Phosphorus	0.32

grade" and was provided compliments of American Colloid Company, Skokie, Ill.

On day one of the experiment, residual hay was removed from all bunks and the lambs were offered 1.36 kg of the treatment diets per head. This was estimated to be in excess of their first days feed intake, but all feed was consumed. On the second day, the lambs received 1.82 kg of their respective treatment diets and were fed *ad libitum* thereafter.

Lambs were individually weighed at approximately 21-day intervals. Feed offered to each pen was recorded daily. The data were corrected by subtacting the inorganic treatment portion of the diet prior to performing statistical analyses on feed intake and feed efficiency. During the experiment, 18 lambs died and performance data were adjusted accordingly. Upon death, animals were taken to the South Dakota Animal Disease Research and Diagnostic Laboratory for necropsy. Lambs were weighed approximately 24 hours prior to slaughter. The average weight at this time was 51.9 kg. Kidneys and bladders were removed at slaughter and examined at a later time for urinary calculi.

Performance data were analyzed by a least-square means analysis of variance procedure as a 2 x 2 x 2 factorial experiment. A Chi-square test was applied to data concerning deaths due to acidosis and the incidence of urinary calculi.

Experiment 2.

Steers of predominantly Hereford breeding and having an average weight of 405.5 kg were used in this study. Prior to the beginning of the experiment, all steers were offered alfalfa-brome hay *ad libitum* for 3 weeks. The feeding trials lasted for an average of 93 days. On day one of the high-concentrate feeding regime all steers were implanted with 36 mg of Synovex-S.

There were four dietary treatments during the first 21 days (phase 1) of the experiment: control, 2% sodium bentonite, 2% sodium bicarbonate, and 2% sodium bentonite plus 2% sodium bicarbonate. Due to the anticipated stress brought on by the relatively short period allowed for adaptation to the high-concentrate diets, three replications of each dietary treatment were carried out separately to lower the risks of extensive losses. For each replication, animals were randomly allotted to four pens, 57 m^2 in area, based on a weight taken approximately 18 hours after feed and water had been removed. Each pen contained five to six animals. During phase 2 (days 22-93), the level of sodium bentonite or sodium bicarbonate supplementation for all dietary treatments was reduced by one-half. All pens had automatic waterers and there were 6.25 m of bunk space per pen.

The control diet was made up of the same ingredients as in Experiment 1 (Table 1) and these were included in the same proportions, except vitamin A, which was fed at 2200 IU per kg of diet. Results from calcium, phosphorus and proximate analysis of a pooled sample from all control mixes prepared during the experiment are presented in Table 3. Phosphorus and proximate analyses were by A.O.A.C. (1975) methods and calcium was determined by atomic absorption spectrophotometry.

Sodium bicarbonate and sodium bentonite were generously provided by the same sources as in Experiment 1 and were added at the expense

TABLE 3. PROXIMATE AND MINERAL ANALYSES OF BASAL DIET, DRY BASIS, EXPERIMENT 2.

Item	Percent
Ether extract	3.30
Crude fiber	5.15
Crude protein	13.18
Ash	3.74
Nitrogen-free extract	74.63
Calcium	0.50
Phosphorus	0.29

of the complete mix diet.

Bringing the animals on feed was accomplished by feeding 2.27 kg of the complete mix on day one with increases of 2.27 kg each day thereafter until animals were eating ad libitum. Steers were weighed individually at approximately 21-day intervals. Feed consumption was measured daily for the entire pen and the inorganic treatment portion was subtracted prior to the statistical analysis of feed consumption and feed efficiency data. A final weight was taken after an approximately 18 hr period without feed or water. Slaughter took place within 6 hr of the final weighing. The average weight at this time was 542.2 kg. Kidneys and bladders were removed at this time to be examined for urinary calculi. The number of abscessed livers was recorded at the time of slaughter and carcass data were collected approximately 24 hours after slaughter.

Data concerning the frequency of liver abscesses and the incidence of urinary calculi were analyzed by a Chi-square test. Performance data and carcass information were analyzed by a least-squares means analysis of variance procedure and treatment means were compared with the control by Dunnett's test.

Results and Discussion

Experiment 1

The result of the abrupt change made in the lamb's diets from alfalfa-brome hay to their respective high-concentrate diets was a generalized condition of rumen acidosis. The severity of the acidosis suffered by the lambs was extremely variable, but the clinical symptoms observed were very similar to those described by Bhattacharya and Warner (1967), Dunlop (1972), Jensen and Mackey (1965), Merck (1973), and Uhart and Carroll (1967). Most lambs appeared to be sick by the third day of the experiment and were extremely stiff and lame. Most of the animals were off feed and were suffering from varying degrees of diarrhea. The first lamb died the evening of the third day.

From this time on, most of the lamb's appetites returned quickly and they recovered from their lameness and diarrhea. Some lambs never regained their appetites, became extremely weak, and eventually died. Upon necropsy examination, rumen pH ranged from 4.0 to 5.0, there were extensive gastric lesions and hemorrhaging and cerebral and pulmonary edema. It was concluded that the lambs had died as a result of rumen acidosis. These findings are in agreement with those of Jensen and Mackey (1965) and Vestweber and Leipold (1974).

Death losses resulting from rumen acidosis are presented in Table 4. The treatment groups had fewer ($P<.01$) death losses than did the group receiving the basal diet. The 19% death loss occurring in the control group was lower than a 31% loss due to acidosis reported by Vestweber *et al*. (1974) to have occurred under similar conditions. All three treatments appeared to offer a high degree of protection

TABLE 4. DEATH LOSSES FROM ACIDOSIS DURING PHASE 1, EXPERIMENT 1

Treatment[a]	No. of Deaths[b]
Basal	12
2% Bentonite	2
2% $NaHCO_3$	2
2% Bentonite + 2% $NaHCO_3$	0

[a]64 lambs per treatment group initially.

[b]Treatments are significantly ($P<.01$) lower than control.

from the deleterious effects of rumen acidosis with death losses amounting to only 3% in the sodium bentonite and sodium bicarbonate groups, and 0% loss in the combination group. Although lambs receiving the treated diets became sick, they recovered quickly, had normal feedlot performance, and most importantly suffered very little death loss. The protection offered by the treatment materials has also been noted by Huntington et al. (1977a, 1977b) and Slanina et al. (1975). Similar results were reported by Calhoun and Shelton (1969) feeding 3% of a 2:1 mixture of magnesium hydroxide and potassium bicarbonate.

The protective action of sodium bicarbonate against rumen acidosis can be explained by its effect of maintaining a more normal pH level in the rumen which supplements the body's buffering capabilities (Emmanuel et al., 1970; Prasad et al., 1973; Prigge et al., 1975). Another possible explanation has been offered by Lee and Matrone (1971). Feeding a purified diet with 6% sodium bicarbonate plus 4% potassium bicarbonate, these workers reported that Na^+ and K^+ supplementation resulted in more L^+ lactic acid than the D^+ form and lowered the acetate to propionate ration in rumen contents. The protective mechanism offered by sodium bentonite may be in maintaining a more normal rumen pH (Prigge et al., 1975; Slanina et al., 1973a).

Performance data for phase 1 are presented in Table 5. Due to the short time interval (21 days) and severe stress, variation within treatments was large in phase 1. Highest feed consumption (ADR) and average daily gain (ADG) (nonsignificant) were obtained from lambs fed diets with the combination of 2% sodium bentonite plus 2% sodium bicarbonate. Feed consumption for the lambs receiving sodium

TABLE 5. MEANS FOR AVERAGE DAILY RATION, AVERAGE DAILY GAIN AND FEED/GAIN, PHASE 1, EXPERIMENT 1.

Treatment, phase 1/phase 2	ADR, kg	ADG, g	F/G
Basal/Basal	.849	154	692
Basal/Basal	.870	175	595
2% Bentonite/Basal	.755	113	1097
2% Bentonite/1% Bentonite	.999	246	414
2% $NaHCO_3$/Basal	.833	136	845
2% $NaHCO_3$/1% $NaHCO_3$	.866	157	613
2% Bentonite + 2% $NaHCO_3$/ Basal	1.028	249	422
2% Bentonite + 2% $NaHCO_3$/ 1% Bentonite + 1% $NaHCO_3$	1.017	202	507

bicarbonate alone differed only slightly from those receiving the basal diet. This is in agreement with Tremere et al. (1968) who reported that sodium bicarbonate supplementation did not change the number of days dairy heifers were off feed after experiencing rumen acidosis.

The statistical analysis indicates that bentonite improved ($P < .05$) feed intake for lambs during the adaptation phase. This includes both the lambs receiving 2% sodium bentonite and those receiving the 2% sodium bentonite plus 2% sodium bicarbonate. This is in agreement with results reported by Huntington et al. (1977b) with lambs and Burkitt (1969) with beef cattle.

Performance data for phase 2 (days 22-75) are shown in Table 6. None of the treatment diets improved performance during phase 2 when lower levels of the materials were fed. This is in agreement with the findings of Huntington et al. (1977b) indicating that the advantages derived from feeding buffering materials occur during adaptation to high-concentrate diets, and this advantage is not sustained throughout the remainder of the finishing period. Cumulative data at the end of the experiment (Table 7) support this. The early advantage for the lambs receiving the combination treatment was not evident when averaged over the entire 75-day experiment.

The effect of sodium bentonite and sodium bicarbonate of increasing the acetate to propionate ratio in dairy cattle fed high-grain diets may explain why leaving the materials in the lamb's diets did not seem to be advantageous. With the increase in the relative percentage of acetic acid, the decreased efficiency of energy

TABLE 6. MEANS FOR AVERAGE DAILY RATION, AVERAGE DAILY GAIN AND FEED/GAIN, PHASE 2, EXPERIMENT 1.

Treatment, phase 1/phase 2	ADR, kg	ADG, g	F/G
Basal/Basal	1.441	280	520
Basal/Basal	1.472	275	541
2% Bentonite/Basal	1.463	290	507
2% Bentonite/1% Bentonite	1.540	296	522
2% $NaHCO_3$/Basal	1.438	271	544
2% $NaHCO_3$/1% $NaHCO_3$	1.468	287	511
2% Bentonite + 2% $NaHCO_3$/ Basal	1.425	270	535
2% Bentonite + 2% $NaHCO_3$/ 1% Bentonite + 1% $NaHCO_3$	1.523	286	533

TABLE 7. MEANS FOR AVERAGE DAILY RATION, AVERAGE DAILY GAIN AND FEED/GAIN, 75 DAYS, CUMULATIVE EXPERIMENT 1.

Treatment, phase 1/phase 2	ADR, kg	ADG, g	F/G
Basal/Basal	1.276	245	525
Basal/Basal	1.304	247	528
2% Bentonite/Basal	1.263	239	525
2% Bentonite/1% Bentonite	1.390	282	495
2% $NaHCO_3$/Basal	1.269	232	553
2% $NaHCO_3$/1% $NaHCO_3$	1.300	251	518
2% Bentonite + 2% $NaHCO_3$/ Basal	1.314	264	504
2% Bentonite + 2% $NaHCO_3$/ 1% Bentonite + 1% $NaHCO_3$	1.382	262	527

metabolism known to accompany this change may outweigh other possible beneficial effects.

The results of the examination of kidneys and urinary bladders for the presence of urinary calculi are presented in Table 8. There was an 8.8% incidence of urinary calculi in the lambs that received sodium bicarbonate and sodium bicarbonate plus sodium bentonite. Lambs receiving the basal or sodium bentonite diets had a 3.6% incidence of urinary calculi. The difference in relative percentages between the lambs receiving diets with and without sodium bicarbonate appears large. However, the total number of lambs involved was not large enough to allow for a sensitive determination of statistical significances.

TABLE 8. INCIDENCE OF URINARY CALCULI, EXPERIMENT 1.

Treatment phase 1	Treatment phase 2	Calculi incidence
Basal	Basal	4/21
	Basal	0/27
2% Bentonite	Basal	0/31
	1% Bentonite	0/31
2% $NaHCO_3$	Basal	2/28
	1% $NaHCO_3$	2/30
2% Bentonite + 2% $NaHCO_3$	Basal	4/26
	1% Bentonite + 1% $NaHCO_3$	2/30

Experiment 2

The steers fed 2.27 kg per head of the high concentrate diet the first day with subsequent increases of 2.27 kg per head daily went off feed between the fifth and sixth day. Daily feed records indicate that the steers receiving 2% sodium bicarbonate or the combination of sodium bicarbonate and sodium bentonite did not go off feed to the same degree as those receiving the basal diet or sodium bentonite alone. Some of the steers became stiff and all animals exhibited varying degrees of diarrhea. All animals appeared to be consuming normal amounts of feed by the twelfth day. There were no deaths due to rumen acidosis during the experiment.

Performance data are shown in Table 9. By the end of the first 21-day period there were only small differences in ADR, ADG and F/G for steers fed the control diet, 2% sodium bentonite or 2% sodium bicarbonate. Those fed the combination of these two materials showed a 16% increase in ADR and a 41% improvement in ADG during period 1. However, variation within treatments was large and the differences proved to be nonsignificant.

Continued feeding of sodium bicarbonate with or without sodium bentonite tended to give lower ADG by the end of the average 93-day feeding periods. This negative effect of sodium bicarbonate on weight gains was evident during phase 2 (days 22-93). However, there were no significant differences in cumulative data over the full term of the average 93-day feeding periods.

These data are in agreement with those reported by other workers. In general, low levels of bentonite (2 - 3.7%) in high-concentrate

TABLE 9. MEANS FOR AVERAGE DAILY RATION, AVERAGE DAILY GAIN AND FEED/GAIN, EXPERIMENT 2.

Weigh periods	Basal	Bentonite	$NaHCO_3$	Combination
Phase 1[a]				
ADR, kg	8.1	8.3	8.2	9.4
ADG, kg	1.5	1.5	1.6	2.1
F/G	551	554	508	462
Phase 2[b]				
ADR, kg	12.2	11.7	11.3	11.7
ADG, kg	1.7	1.6	1.5	1.4*
F/G	705	753	762	845
End of experiment,[c] filled weight				
ADR, kg	11.2	10.9	10.6	11.1
ADG, kg	1.7	1.6	1.5	1.6
F/G	673	703	690	721
End of experiment,[c] shrunk weight				
ADR, kg	11.3	10.9	10.6	11.2
ADG, kg	1.6	1.6	1.5	1.5
F/G	698	699	703	743

[a] 21 days, cumulative, 2% level of treatment materials.

[b] days 22 to 93, 1% level of treatment materials.

[c] 93 days, cumulative.

* Significantly lower than control ($P < .05$).

rations for beef cattle have not proved to be beneficial in terms of overall feedlot performance (Burkitt, 1969; Erwin et al., 1957; Marshall and VanHorn, 1973; Schake and Garner, 1976; Slanina et al., 1973b). Here again, the explanation may lie in research done with dairy cattle. Bentonite fed in high-concentrate diets has been found to increase the acetate to propionate ratio in the rumen (Bringe and Schultz, 1969; Rindsig et al., 1969). This would be expected to depress weight gain as acetic acid is not metabolized by the ruminant to provide as much net energy as is obtained from propionic acid.

Response to dietary sodium bicarbonate has been variable. Some workers have obtained improved performance in beef cattle with the use of sodium bicarbonate (Brethour and Duitsman, 1973a; Kellaway et al., 1973; Nicholson and Cunningham, 1961). However, this has not been the case in many other instances where there was no improvement of feedlot performance with levels of sodium bicarbonate and mixed buffers from 1 to 10% of high-concentrate diets (Embry et al., 1969; Nicholson et al., 1962a; Nicholson et al., 1963b; Wise et al., 1961; Wise et al., 1965). Similar to reports discussed above pertaining to bentonite, these levels of alkaline materials have been shown to increase the acetate to propionate ratio in dairy cattle (Davis et al., 1964; Emery et al., 1965; Huber et al., 1969; Miller et al., 1965). This would be expected to decrease the efficiency of energy metabolism.

In agreement with the results of Experiment 1 with lambs, there was a trend toward improved performance during the initial 21 days with the feeding of a combination of 2% Sodium bentonite and 2% sodium bicarbonate. A depression in ADG associated with this treatment in phase 2 may be attributed to its effect in depressing the efficiency of energy metabolism.

Feeding diets high in concentrates has been associated with a high degree of liver abscesses (Jensen et al., 1954). These workers reported a positive correlation between gastric lesions and liver abscesses. Considering sodium bicarbonate's and sodium bentonite's effect on ruminal pH, it may be hypothesized that they may aid in the prevention of liver abscesses by reducing acidosis and associated digestive tract lesions. The incidence of liver abscesses is presented in Table 10. In each the control and the sodium bentonite treatment groups, four of 17 to 18 animals (22%) had abscessed livers. In groups receiving sodium bicarbonate or the combination treatment, one to two animals of 18 (average 6%) had abscessed livers. While the relative percentage difference may appear large, the number of animals involved was not adequate to allow a sensitive determination of statistical significance.

The incidence of urinary calculi is presented in Table 11. In accordance with work reported by Hoar et al. (1969) and Huntington, et al. (1977b) supplemental sodium bicarbonate had a tendency to increase the incidence of urinary calculi. In the groups receiving the basal diet or the sodium bentonite treatment, there was an average 40% incidence of urinary calculi. However, the average incidence for the sodium bicarbonate and combination treatments was 61%. Here again, the number of animals involved were not adequate to allow a sensitive determination of statistical significance.

TABLE 10. INCIDENCE OF LIVER ABSCESS, EXPERIMENT 2.

Treatment	Liver abscess incidence
Basal	4/17
Bentonite	4/18
$NaHCO_3$	2/18
Bentonite + $NaHCO_3$	1/18

TABLE 11. INCIDENCE OF URINARY CALCULI, EXPERIMENT 2.

Treatment	Calculi incidence
Basal	6/17
Bentonite	8/18
$NaHCO_3$	12/18
Bentonite + $NaHCO_3$	10/18

Carcass data are presented in Table 12. Neither sodium bentonite, sodium bicarbonate or the combination had any effect on the carcass data analyzed.

Summary

Sodium bentonite and sodium bicarbonate, each fed as 2% of the diet alone and in combination, offered lambs a high degree of protection against death losses occurring from rumen acidosis during a very abrupt change from a high-roughage to a high-concentrate diet. Beneficial effects on performance of lambs and steers, when occurring, appear to be restricted to the very early period of adaptation to high-concentrate diets. Neither beneficial nor harmful effects have been found to be associated with the continued feeding of these materials to lambs during the remainder of the finishing period. Sodium bicarbonate as 1% of the diet appears to depress gain if left in the diets of steers for the entire finishing period.

TABLE 12. LEAST SQUARE MEAN CARCASS SCORES, EXPERIMENT 2.

Item	Basal	Bentonite	$NaHCO_3$	Combination
Dressing percent	60.8	60.6	60.4	60.7
Marbling score[a]	4.4	4.6	4.9	4.4
Quality grade[b]	18.0	18.2	18.6	17.8
Yield grade[c]	2.8	2.7	2.8	2.7

[a]Small = 5; slight = 4.

[b]Choice = 20; Good + 17. Graded to one-third of a grade.

[c]USDA yield grade 1, 2, 3, 4, 5.

EXPERIMENT 3: LIMESTONE IN HIGH CONCENTRATE DIETS FOR LAMBS

Introduction

Limestone is a common feed ingredient used primarily for increasing the calcium content of various diets. In recent years there has been evidence that levels of limestone higher than those commonly recommended may have beneficial effects for feedlot ruminants in preventing phosphatic urinary calculi and increasing weight gains. The objectives of this experiment were to study graded levels of limestone as buffering agents during rapid adaptation to high-concentrate diets and to observe the effects, if any, of leaving the material in the diet at the same levels.

Experimental Procedure

This experiment utilized 160 cross-bred lambs of Texas origin. Average initial weight was 27.6 kg. All lambs received alfalfa-brome hay *ad libitum* for 4 weeks prior to the beginning of the experiment. They were vaccinated for the prevention of enterotoxemia and drenched for the control of internal parasites.

Based on initial filled weight, the lambs were randomly allotted to 16 outdoor pens with five ewes and five wethers per pen. The pens were 24 m^2 in area, were equipped with automatic waterers and had 4.9 m of bunk space.

The experiment had four dietary treatments with four replications per treatment group. The treatments were a control, 1% limestone, 2% limestone and 4% limestone. The feeding trial lasted for 121 days.

The basal diet was identical to that in Experiment 1 (Table 1). The limestone used was feed grade, maximum 39.6% and a minimum 39.2% calcium. Individual mixes for each treatment were sampled and a pooled sample for each of the treatments was analyzed by proximate analyses and for calcium and phosphorus. Phosphorus and proximate analyses were by A.O.A.C. (1975) methods, and the calcium analysis was by atomic absorption spectrophotometry. Results of the analysis of the basal diet are presented in Table 13.

Residual hay was removed from all the feed bunks on day one of the experiment and the lambs were offered 1.36 kg per head of their respective diets. They were fed ad libitum thereafter. The lambs were weighed individually at approximately 21-day intervals and feed consumption was recorded daily for each pen. Feed efficiency and average daily feed intakes were calculated on a pen basis after the limestone portion had been subtracted from the amount fed.

Lambs that died during the experiment were necropsied by the South Dakota Animal Disease Research and Diagnostic Laboratory. Performance data were adjusted for each lamb removed from the experiment by subtracting an average feed consumption up to that time. Performance data are reported only for those lambs that finished the experiment. The lambs were slaughtered approximately 18 hours after their final weights were taken. Average weight at time of slaughter was 54.6 kg. Kidneys and bladders were collected from each animal at the time of slaughter and examined for urinary calculi. Carcass data were collected 24 hours after slaughter.

TABLE 13. PROXIMATE AND MINERAL ANALYSES OF BASAL DIET, DRY BASIS, EXPERIMENT 3.

Item	Percent
Ether extract	2.19
Crude fiber	5.16
Crude protein	13.95
Ash	4.45
Nitrogen free extract	74.25
Calcium	0.59
Phosphorus	0.35

Feedlot performance and carcass data were analyzed by a least-square means analysis of variance procedure. Statistical differences were determined by Dunnett's test. A Chi-square test was applied to data concerning deaths due to acidosis and the incidence of urinary calculi.

Results and Discussion

Severe rumen acidosis resulted when lambs were offered the high-concentrate diet after receiving alfalfa-brome hay for 4 weeks. The clinical signs observed were identical to those described in Experiment 1. Lambs began dying the third day of the experiment. Examination after death showed rumen pH values from 4.0 to 5.0, severe gastric ulcers and bleeding, and pulmonary and cerebral edema. Deaths attributed to acidosis in each treatment group are presented in Table 14. There was a 25, 35, 22.5 and 10% death loss in the 0, 1, 2 and 4% supplemental limestone groups, respectively. The 10% loss in the 4% limestone group approached being significantly lower ($P<.10$) than the loss occuring in the control group. This trend indicates that the optimum level of limestone supplementation for preventing adverse effects of rumen acidosis during adaptation to high-concentrate diets may not have been reached in this study.

Survivors in the control group receiving the basal diet did not recover quickly. This was reflected in feedlot performance during period 1, as shown in Table 15. All limestone treatments improved ($P<.01$) feed intake and increased ($P<.01$) ADG during period 1 when

TABLE 14. DEATH LOSSES FROM ACIDOSIS DURING ADAPTATION PERIOD, EXPERIMENT 3.

Treatment	No. of Deaths[a]
Basal	10
1% limestone	14
2% limestone	9
4% limestone	4[b]

[a]40 lambs per treatment group initially.

[b]Differs significantly from control ($P < .10$).

TABLE 15. MEANS[a] FOR AVERAGE DAILY RATION, AVERAGE DAILY GAIN AND FEED/GAIN, EXPERIMENT 3.

Weigh Periods	Limestone treatments, %			
	0	1	2	4
Period 1, 22 days				
ADR, kg	0.674	0.796**	0.891**	0.901**
ADG, g	54	163**	178**	201**
F/G	1090	488	529	469
Period 2, 43 days				
ADR, kg	0.920	1.128*	1.101*	1.099*
ADG, g	213	278	254	271
F/G	434	413	438	424
Period 3, 64 days				
ADR, kg	1.066	1.210	1.193	1.190
ADG, g	228	278	260	261
F/G	472	442	466	477
Period 4, 86 days				
ADR, kg	1.117	1.265	1.201	1.204
ADG, g	235	290	235	243
F/G	480	443	529	516
Period 5, 107 days				
ADR, kg	1.167	1.305	1.220	1.245
ADG, g	213	255**	227	230
F/G	553	517	552	564
Period 6, 121 days				
ADR, kg	1.200	1.312	1.231	1.253
ADG, g	209	246**	214	223
F/G	581	545	597	585

[a] Data are cumulative.

* Differs significantly from control ($P < .05$).

** Differs significantly from control ($P < .01$).

compared to lambs receiving no supplementation. The improvement ($P<.05$) in ADR for all the treatment groups carried over into period 2 as well.

ADR and ADG for lambs at all levels of limestone supplementation were equal to, or greater than, the controls throughout the experiment. However, in periods 3 and 4 differences between treatments were not significant. By period 5, 1% added limestone significantly ($P<.01$) improved ADG when compared to lambs receiving the basal diet. This improvement ($P<.01$) in ADG was also evident for the lambs receiving the 1% limestone supplementation at the end of the experiment. This amounted to an 18% improvement in ADG and indicates that 1% may be the optimum level of limestone supplementation in terms of feedlot performance following adaptation.

In the past, results from limestone supplementation have been variable. Some reports have indicated limestone supplementation to have little effect on performance of beef cattle (Embry *et al.*, 1968; Embry *et al.*, 1969). However, Klosterman *et al.*, (1960) reported that the addition of 1% limestone to corn silage at the time of ensiling raised the pH of the silage one-half unit and increased organic acid production. When fed to beef cattle, the treated silage improved weight gains when compared to animals receiving corn silage that was not treated. Barth *et al.*, (1974) found very similar results with 0.5% limestone added to urea-treated silage.

Tremere *et al.* (1968) reported that a 5% level of sodium bicarbonate in a high-concentrate diet had no effect on days off feed after acidosis. But data reported herein indicate that levels of

1 to 4% limestone did reduce the days off feed. Limestone supplementation not only improved ADR during the first 3 weeks but the improvement continued through the sixth week as well.

Results from studies concerning the effects of limestone inside the gastrointestinal tract offer several possible explanations for the improved ADG with 1% limestone supplementation in this experiment. Prigge et al. (1975) reported that 2% calcium carbonate supplementation resulted in higher free-fatty acid production when compared to feeding the same level of sodium or potassium bicarbonate. Very recent work with sheep indicates that limestone and magnesium limestone raises intestinal pH providing a more favorable environment for pancreatic alpha amylase which results in an extensive drop in the amount of undigested starch remaining in the feces (Wheeler and Noller, 1977).

Carcass data were collected 24 hours after slaughter and are presented in Table 16. There were no differences in carcass characteristics between treatment groups. Kidneys and bladders were examined after slaughter for the presence of urinary calculi. The incidence of urinary calculi in each experimental group is presented in Table 17. There were no differences in the incidence of calculi. It was determined that the calculi were predominantly silicious in nature, and they are believed to have been present prior to the time that the animals were placed on experiment.

Summary

Death loss due to acidosis was extremely high for all groups and ranged from 10 to 35%. Even the 10% loss occurring in the 4%

TABLE 16. LEAST SQUARE MEAN CARCASS SCORES, EXPERIMENT 3.

	Level of limestone, %			
Item	0	1	2	4
Dressing percent	53.3	52.5	53.7	52.5
Grade[a]	12.4	12.1	12.4	12.6
Conformation[a]	13.5	13.0	13.2	13.7
Maturity[b]	2.1	2.2	2.2	2.1
Flank streaking[c]	13.3	13.1	13.6	13.6
Feather[c]	15.9	15.5	16.2	16.6

[a]Choice = 11; Prime = 14. Graded to one-third of a grade.

[b]A- maturity = 1; A+ maturity = 3.

[c]Traces = 8; slight = 11; small = 14; modest = 15; moderate = 16.

TABLE 17. INCIDENCE OF URINARY CALCULI, EXPERIMENT 3.

Treatment	Calculi incidence
Basal	3/29
1% limestone	2/22
2% limestone	1/31
4% limestone	4/35

limestone group would be unacceptable for commercial lamb feeders. This indicates that higher levels of limestone may be necessary to prevent the death loss associated with rumen acidosis during rapid adaptation to high-concentrate diets.

Improvement in ADR and ADG during the adaptation phase was observed for all three levels of supplementation. Limestone supplementation allowed the lambs to recover quickly and make acceptable weight gains during a rapid adaptation period.

The 2 and 4% levels of limestone appeared to be too high to give optimum results over the entire 121-day feeding period, but the 1% level resulted in an 18% improvement in ADG. This response is adequate to be of potential economic importance to commercial lamb feeders.

SUMMARY

Three experiments were undertaken to evaluate sodium bentonite, sodium bicarbonate and limestone supplementation for ruminants in terms of protection that they may provide from rumen acidosis associated with an abrupt change from roughage to a high-concentrate diet, and to determine effects of these materials on overall performance when fed to ruminants throughout the feeding period.

In Experiment 1, four treatments including a control, 2% sodium bentonite, 2% sodium bicarbonate, and 2% sodium bentonite plus sodium bicarbonate were incorporated into a high-concentrate (8% hay) diet for lambs. The experimental design was a 2 x 2 x 2 factorial with eight pens per treatment and eight lambs per pen. On day one, alfalfa brome hay comprising the pretreatment diet was removed from the feedbunks and the lambs were fed the high-concentrate diets at a rate of 1.36 kg per head. They were fed _ad libitum_ thereafter. These treatment diets were fed for 21 days (phase 1). After phase 1, sodium bentonite and sodium bicarbonate were withdrawn from the diets for one-half of the treated lambs and reduced to 1% of the diet for the remainder. These diets were fed during days 22 to 75 of the experiment (phase 2). Death losses resulting from rumen acidosis during phase 1 were 19, 3, 3 and 0% for the control, 2% sodium bentonite, 2% sodium bicarbonate, and 2% sodium bentonite plus 2% sodium bicarbonate groups, respectively. When compared with controls, death losses for all other groups were significantly ($P<.01$) lower. Beneficial effects of supplementation on performance, when occuring, appeared to be restricted to the early

period of adaptation to the high-grain diets. Effects of the two materials fed in combination did not appear to be additive.

Experiment 2 was conducted with steers. The four treatments were the same as those used in Experiment 1. Three replications were carried out at various times with 6 steers per pen. Phase 1 was from days 1 to 21 and phase 2 was from days 22 to 93. Animals were brought to full feed in 5 days but no steers were lost as a result of rumen acidosis. In concurrance with the results of Experiment 1, the beneficial effects of these materials appeared to be restricted to phase 1. Sodium bicarbonate had a tendency to depress performance in phase 2.

In Experiment 3, limestone was incorporated into high-concentrate diets at levels of 0, 1, 2 and 4% for 160 feeder lambs. There were four pens per treatment group with 10 lambs per pen initially. Their diets were abruptly changed from alfalfa-brome hay to 1.36 kg of their respective high-concentrate diets on the first day of the experiment. They were fed ad libitum thereafter. Death losses attributed to rumen acidosis from each treatment amounted to 25, 35, 22.5 and 10% in the 0, 1, 2 and 4% supplemental limestone groups, respectively. All three limestone treatments improved ($P<.01$) feed intake and increased ($P<.01$) gain during the first 21 days of the experiment. Over the entire 121-day experiment, 1% limestone supplementation improved ($P<.01$) average daily gain by 18% when compared to lambs receiving the basal diet. This indicates that 1% may be the optimum level of limestone supplementation in terms of feedlot performance following adaptation.

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