Calcium levels in finishing cattle rations
by Randall Keith Dew

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Animal Science
Montana State University

Abstract:
Four feeding trials were conducted with finishing steers to evaluate the effect of ration calcium level on feedlot performance, free-choice, high-calcium mineral consumption, fecal alkalinity, fecal pH, fecal starch content, and carcass merit. In trial I, 64 head of 324 kg. Simmental cross-bred steers were fed a 92% ground barley-8% roughage finishing ration ad libitum for 119 days. The steers were allotted to four treatments which consisted of the following: 1) .3% calcium in the ration, 2) .3% calcium in the ration + free-choice mineral, 3) .6% calcium in the ration, and 4) .6% calcium in the ration + free-choice mineral. Daily gain, feed per gain, daily ration intake, free-choice mineral consumption, fecal pH, fecal alkalinity, fecal starch content, and carcass merit were not found to be significantly different ($P > .05$) among treatments. Fecal starch was found not to be correlated ($P > .05$) with fecal pH. In trial II, 48 head of 275 kg. cross-bred steers were fed an 85% ground barley and wheat, 15% roughage finishing ration for 192 days. The steers were allotted to four treatments which consisted of the following: 1) .15% calcium, 2) .3% calcium, 3) .6% calcium, 4) .9% calcium in the ration dry matter. Among the four treatments there was no significant ($P > .05$) difference found in daily gain, feed per gain, daily feed intake, or fecal starch content. Fecal pH for steers fed treatment 4 (6.7) was greater ($P < .01$) than for cattle fed treatments 1 (6.1) and 2 (6.2). Fecal starch was found to be negatively correlated ($r = -.38$; $P < .01$) with fecal pH. Regression analysis indicated that 38% of the variation of fecal pH was due to a treatment effect. Quality grade for cattle fed treatment 4 was lower (11.5 vs. 12.5 and 12.4) than for cattle fed treatments 1 ($P < .01$) and 3 ('$P < .05$). Also cattle fed treatment 4 had a lower marbling score ($P < .01$) than did cattle fed treatment 3. In trial III, 40 head of 235 kg. cross-bred steers were fed a high-roughage, low-grain growing ration for 56 days. The roughage was fed ad libitum and the grain mix intake limited to 1.0% of the steers' body weight per day. The steers were allotted to one of four treatments which consisted of the following: 1) .24% calcium, 2) .6% calcium, 3) 1.0% calcium, and 4) 1.9% calcium in the ration dry matter. Average daily gain, feed per gain, and daily ration intake were not found to be significantly affected ($P > .05$) by the four treatments. In trial IV, the steers used in trial III were fed an 85% ground barley and wheat, 15% roughage finishing ration for 178 days. The same ration calcium level treatments fed in trial II were used in trial IV. Neither of the four treatments were found to significantly ($P > .05$) improve daily gain, feed per gain, daily ration intake and carcass merit, or reduce fecal starch content. Steers fed treatment 4 did have a higher ($P < .05$) fecal pH (6.6 vs. 6.2) than did steers fed treatment 1. Regression analysis indicated that 24% of the variation in fecal pH ($P < .01$) was due to a treatment effect.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Randall K. Dean

Date 12/2/81

CALCIUM LEVELS IN FINISHING CATTLE RATIONS

by

RANDALL KEITH DEW

A thesis submitted in partial fulfillment
of the requirements for the degree

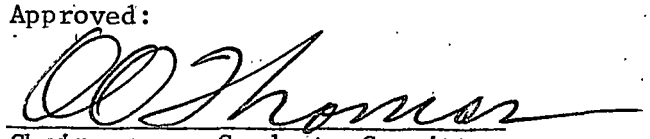
of

MASTER OF SCIENCE

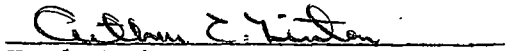
in

Animal Science

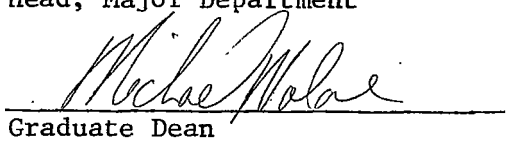
Approved:



Chairperson, Graduate Committee



Head, Major Department



Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1981

ACKNOWLEDGEMENTS

I would like to express my sincere graditude to my major professor, Dr. O. O. Thomas, for his patience and invaluable guidance throughout my graduate program in the organization and implementation of the experiments and his suggestions in the preparation of this thesis. My graditude also goes out to Dr. B. R. Moss for his suggestions and time taken in proofreading, and to Dr. L. L. Jackson, Dr. R. E. Lund and Mr. Ray Ansotegui for their helpful ideas and comments. I would also like to thank Mr. Ron Thorson for his assistance with my data and in using the computer.

The lab analysis portion of this thesis would not have been possible without the suggestions and encouragement of Dr. N. J. Roth and Gayle Watts. I also owe my thanks to Bob Richard and his staff for their management of and assistance with the trials.

My thanks also goes out to Evelyn Richard for typing the manuscript and to Anne Angermeyer for her expertise in handling samples.

Finally, I owe my individual and special thanks to my wife Nancy and my parents Keith E.and Dorthy V. Dew for their encouragement, support, and guidance, without which no graduate program would have been attempted.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Four feeding trials were conducted with finishing steers to evaluate the effect of ration calcium level on feedlot performance, free-choice, high-calcium mineral consumption, fecal alkalinity, fecal pH, fecal starch content, and carcass merit. In trial I, 64 head of 324 kg. Simmental cross-bred steers were fed a 92% ground barley-8% roughage finishing ration ad libitum for 119 days. The steers were allotted to four treatments which consisted of the following: 1) .3% calcium in the ration, 2) .3% calcium in the ration + free-choice mineral, 3) .6% calcium in the ration, and 4) .6% calcium in the ration + free-choice mineral. Daily gain, feed per gain, daily ration intake, free-choice mineral consumption, fecal pH, fecal alkalinity, fecal starch content, and carcass merit were not found to be significantly different ($P > .05$) among treatments. Fecal starch was found not to be correlated ($P > .05$) with fecal pH. In trial II, 48 head of 275 kg. cross-bred steers were fed an 85% ground barley and wheat, 15% roughage finishing ration for 192 days. The steers were allotted to four treatments which consisted of the following: 1) .15% calcium, 2) .3% calcium, 3) .6% calcium, 4) .9% calcium in the ration dry matter. Among the four treatments there was no significant ($P > .05$) difference found in daily gain, feed per gain, daily feed intake, or fecal starch content. Fecal pH for steers fed treatment 4 (6.7) was greater ($P < .01$) than for cattle fed treatments 1 (6.1) and 2 (6.2). Fecal starch was found to be negatively correlated ($r = -.38$; $P < .01$) with fecal pH. Regression analysis indicated that 38% of the variation of fecal pH was due to a treatment effect. Quality grade for cattle fed treatment 4 was lower (11.5 vs. 12.5 and 12.4) than for cattle fed treatments 1 ($P < .01$) and 3 ($P < .05$). Also cattle fed treatment 4 had a lower marbling score ($P < .01$) than did cattle fed treatment 3. In trial III, 40 head of 235 kg. cross-bred steers were fed a high-roughage, low-grain growing ration for 56 days. The roughage was fed ad libitum and the grain mix intake limited to 1.0% of the steers' body weight per day. The steers were allotted to one of four treatments which consisted of the following: 1) .24% calcium, 2) .6% calcium, 3) 1.0% calcium, and 4) 1.9% calcium in the ration dry matter. Average daily gain, feed per gain, and daily ration intake were not found to be significantly affected ($P > .05$) by the four treatments. In trial IV, the steers used in trial III were fed an 85% ground barley and wheat, 15% roughage finishing ration for 178 days. The same ration calcium level treatments fed in trial II were used in trial IV. Neither of the four treatments were found to significantly ($P > .05$) improve daily gain, feed per gain, daily ration intake and carcass merit, or reduce fecal starch content. Steers fed treatment 4 did have a higher ($P < .05$) fecal pH (6.6 vs. 6.2) than did steers fed treatment 1. Regression analysis indicated that 24% of the variation in fecal pH ($P < .01$) was due to a treatment effect.

Chapter 1

INTRODUCTION

The existence of the beef industry as it is known today is threatened by such factors as rising feed costs, interest rates, labor costs and reduced consumer demand with increased competition of meat from other species. The challenge facing the beef industry was expressed by Dr. W. T. Berry, Jr., executive vice president of the National Cattlemen's Association, who said in 1981, "Beef producers have lost their market to the tune of 20 percent since 1974, beef consumption in this country has dropped from 96 lb. per person to 78 lb. of beef at the retail level. We are in a protein battle and are being out produced, out processed and out merchandised by protein products with a lower price." The search for ways to increase economy and efficiency in all phases of beef production must be intensified in response to the various economic pressures being placed on the industry.

The cattle feeder, in particular, is one component of the beef industry whose livelihood is threatened by these economic pressures. Many advancements have been made over the years in maximizing production and improving the efficiency of feeding cattle for slaughter. The most obvious improvement has been a shift from high-roughage, low energy diets to more energy-dense rations consisting primarily of cereal grains and a limited amount of roughage. The more energy-dense

cereal-grain based diets (comprised of at least 80 percent cereal grain) would allow a faster and more economical gain versus grass or high roughage fattened cattle. As recently as 30 to 35 years ago, a typical cattle finishing ration would have consisted of only 40 to 50 percent grain and 50 to 60 percent roughage.

As the feeding of high grain diets became a more common practice, researchers noted that expected rates and efficiencies of production were not always realized (Noller, 1978). In fact, ration digestibility was found to decrease 10 percent or more when high-grain, low-roughage diets have been fed ad libitum to ruminants (Wheeler et al., 1975).

Several digestive disorders inherent with the feeding of high-grain diets are thought to be the major cause of reduced ration digestibility and animal performance. The primary physiological anomaly associated with high-grain diets is the prevalence of acidic conditions throughout the digestive tract of ruminants consuming diets high in readily soluble carbohydrates such as starch. Exogenous buffers have long been used in ruminant nutrition in an effort to combat this acidity and return the pH of the digestive tract to a level conducive for optimum nutrient utilization (Wheeler, 1980a).

Until recently, the focus of attention in the use of buffers has been in the control of pH in the reticulorumen with little concern for the pH environment of the small intestine. However,

recent research has provided evidence that elevating levels of calcium in ruminant rations using limestone (calcium carbonate) results in a higher pH in the small intestine, and improved performance and ration digestibility (Wheeler and Noller, 1977). This increase in small intestinal pH was accompanied by a reduction in the amount of starch appearing in the feces. In addition, the pH of the small intestine was found to be reflected in the pH of the feces.

Researchers have theorized that acidic conditions prevalent in the small intestine hamper the action of the enzyme alpha amylase on rumen-bypassed starch. Therefore, theoretically, ration digestibility and animal performance should be improved by the use of an exogenous buffer such as limestone which is known to be an effective small intestinal buffer.

In an effort to further define the effects of increased calcium levels in finishing cattle rations, four feeding trials were conducted with the following objectives under consideration:

1. Determine whether or not finishing cattle would exhibit improved performance and carcass merit if fed a level of calcium above that recommended by the National Research Council.

2. Determine whether or not ration calcium levels and calcium to phosphorus ratios less than those recommended by the National Research Council affect feedlot performance.

3. Determine whether or not increased calcium intake would affect fecal pH, fecal alkalinity, and the amount of starch in the fecal dry matter, and whether or not these

variables were related to feedlot performance or each other.

4. Determine whether or not ration calcium level would influence the daily intake of a free-choice, high-calcium (21 percent calcium and 7 percent phosphorus) mineral mix.

The subject of this thesis encompasses the results of those four feeding trials in light of the preceding objectives.

The review of literature will deal with the characteristics of high-grain, low-roughage diets fed to ruminants and the various digestive disorders associated with their consumption. The primary disorder to be considered is the reduction of pH throughout the entire ruminant digestive tract and the effect on ration starch digestion. The sites of starch digestion in the ruminant digestive tract will also be discussed. The review will conclude with various citings of the use of limestone as a lower tract buffer and calcium levels in ruminant rations.

Chapter 2

REVIEW OF LITERATURE

Degradation of Starch in the Digestive Tract

Ingested starch is catabolized primarily in the rumen utilizing hydrolytic enzymes produced by micro-organisms, or will be degraded in the small intestine via enzymes secreted in pancreatic fluid in the small intestine, Keller, et al. (1958).

Ruminal Degradation of Starch

In the rumen, starch is considered to be rapidly digested (Hungate, 1966). Rumen micro-organisms produce alpha amylase, an enzyme that will attack the interior of starch molecules. The end result will be the production of maltose, dextrins, and oligosaccharides (French, 1973). Since glucose is not formed directly from the action of this alpha amylase, micro-organisms must also produce maltase and dextrinase enzymes to yield glucose.

Bacteria will provide the principal means whereby starch is degraded to glucose, and glucose in turn fermented to steam-volatile organic acids and lactic acid. The bacteria species of Streptococcus bovis, Bacteroides amylophilus, Bacteroides ruminicola, Succinimonas amylolytica and Selenomonas ruminantium are known to include many starch digesting strains (Hungate, 1966). The Streptococcus bovis strain has been identified as producing an alpha amylase as well as

sucrose phosphorylase, isomaltase, and lactic dehydrogenase. The Bacteroides amylophilus strain is capable only of attacking starch and not glucose. The Succinimonas amylolytica strain, like the Bacteroides amylophilus strain, is unable to ferment glucose, but can act on hydrolysis products of starch (Hungate, 1966).

A large portion of the glucose formed in the rumen is fermented via the Embden - Meyerhof glycolytic pathway to steam volatile organic acids, primarily acetic, propionic, and butyric (Baldwin, 1965). Acids produced in smaller quantities include formic, isobutyric, 2-methylbutyric, valeric and isovaleric (Church, 1969). These acids are then absorbed through the rumen wall into the portal blood and utilized as an energy or glucose source by the ruminant (Blaxter, 1962). Vetter and Stifel (1971) found significant levels of fructose-1-phosphate, fructose-1,6-diphosphate aldolases, hexokinase, glucokinase, fructose-1,6-diphosphatase, pyruvate kinase and glucose-6-phosphate dehydrogenase in the rumen of corn fed steers.

Protozoa to a lesser extent will digest ration starch. The Entodinium species has been found to be the predominant protozoa in grain fed ruminants (Hungate, 1966). Mould and Thomas (1958) found that protozoa will synthesize starch in the form of amylopectin. The workers also determined the presence of alpha amylase, maltase, and amylo-1,6-glucosidase in protazoa cell extracts taken from sheep. Heald (1951), in studies with sheep, determined an

insignificant amount (5 to 6 g//24 hr.) of glucose was presented to the small intestine from protozoa. However, it should be noted the sheep in this trial were on all chopped hay diets with no grain. Weller and Gray (1954) also concluded that protozoa make insignificant contributions of glucose to the small intestine. Hungate (1966) stated that the protozoa will meet about one percent of the daily carbohydrate requirements of the host.

Small Intestinal Digestion of Starch

The means by which starch is degraded in the small intestine to glucose appears to be quite similar between the ruminant and monogastric animals. In both species the pancreas will secrete an aqueous and an organic phase of fluid into the duodenum by the common bile duct (Hill, 1970). However, it appears that in addition to the common bile duct, ruminants also possess a major duct from the pancreas to the duodenum, thereby providing two routes for pancreatic secretions to the small intestine (Wass, 1965).

The aqueous phase is high in sodium bicarbonate and will provide the major means of buffering the small intestine from acids produced in the rumen and the abomasum. The organic phase will contain the enzymes and zymogens responsible for digestion such as: trypsinogen, chymotrypsinogen, procarboxypeptidase A and B, and carboxypeptidase B; nucleolytic enzymes such as ribonuclease and deoxyribonuclease;

lipolytic and amylolytic enzymes. The amylolytic enzymes such as alpha amylase will comprise less than two percent of the enzymes present in the pancreatic secretions. This is considered extremely low compared to the concentration of amylolytic enzymes present in the pancreatic fluid of man (Keller et al., 1958).

Pancreatic alpha amylase catalyzes the hydrolysis of the alpha 1-4 linkages in the interior of the starch polymers presented to the small intestine. The products of this hydrolysis will be maltose, maltotriose and alpha limit dextrans (since most of the ingested starch is amylopectin). The majority of amylase acitivity takes place in the intestinal lumen (Gray, 1970). Dextrinase and maltase enzymes will then catalyze the hydrolysis of the maltose, maltotriose and alpha limit dextrans to glucose (Siddons, 1968). Most likely this hydrolysis takes place within the intestinal columnar cells (Gray, 1970). In the presence of adenosine triphosphate (A.T.P.) and hexokinase, glucose is phosphorylated and actively transported across the cell membrane (Hele, 1950; Gray, 1970).

In the monogastric animal the absorption of glucose begins in the duodenum and is completed in the proximal 100 cm. of the jejunum (Borgstrom et al., 1957). Hembry et al. (1967) in studies with mature sheep found that the greatest amount of glucose uptake occurred in the jejunum. These workers also noted that amylase was the second most abundant carbohydrase enzyme in the small intestine next to maltase,

and concluded that since maltase was plentiful, complete hydrolysis of starch is more dependent on amylase acidivity. Absorption of glucose from the colon was found to be extremely low.

Borgstrom et al. (1957), in intestinal intubation studies with humans, found a wide variation in the concentration of enzymes over the length of the intestine. Hembry et al. (1967), in studies with sheep, found the mucosa of the jejunum contained the greatest amount of all enzymes with the duodenum containing the least.

Large Intestinal Digestion of Starch

Significant amounts of starch escape rumen fermentation and are digested in the large intestine. However, Waldo (1973) indicated that the capacity of the large intestine to digest starch is not well defined.

Karr et al. (1966) suggested that on high concentrate diets more starch may reach the small intestine of cattle than is able to be utilized. In their study, total tract digestion of starch ranged from 97.7 to 98.8 percent, indicating the carbohydrates passing the small intestine undigested were digested quite well in the large intestine. It was also noted 4.3 g/kg b.w. $^{3/4}$ of starch was presented in the large intestine, 83 percent of which was digested in this region of the gut. With increasing levels of starch in the ration, post-ruminal digestion of starch remained high, but increasing

amounts were digested in the large intestine. McNeill et al. (1971), in trials with various forms of sorghum grain, found an average of 6.5 g/kg. $b.w.^{3/4}$ of starch was presented to the large intesting of 370 kg. Angus steers, of which 88 percent was digested.

The mode of starch digestion in the large intestine is primarily that of fermentation by anaerobic micro-organisms, with the subsequent production of steam volatile organic acids such as acetic, propionic, and butyric. These acids are absorbed across the large intestinal wall in the same manner as those produced in the rumen and utilized as an energy source by the ruminant (Orskov et al., 1970).

In considering the economy of post-ruminal starch digestion, starch degraded via enzyme catalysis in the small intestine with the subsequent uptake of glucose will be more efficient than the fermentation of starch in the large intestine. Armstrong et al. (1960) infused glucose into either the rumen or abomasum of sheep fed a basal ration of dried grass. Rumen infused glucose was utilized with 54.5 percent efficiency, with 42.3 kilocalories fat stored per 100 kilocalories of glucose administered. The abomasal infused glucose that bypassed rumen fermentation was utilized with 71.5 percent efficiency with 61.6 kilocalories of fat stored on the animal per 100 kilocalories of glucose administered.

In addition to energy losses from heat, and gasses produced from fermentation, microbial nitrogen synthesized would also be lost as no

digestion of microbes would take place beyond the large intestine. In studies with sheep, Orskov et al. (1970) determined that 1.6 g. of nitrogen was excreted in the feces for every 100 g. of carbohydrate fermented in the large intestine.

Carbohydrase Activity and Development in the Young Ruminant

The young ruminant apparently has limited abilities to degrade starch in the small intestine due to limited amounts of amylase and maltase being produced. Dollar and Porter (1957) gave oral solutions of glucose, lactose, sucrose, maltose, dextrins, and soluble starch to young dairy calves. The workers found that during the first four weeks of life the calves utilized only glucose and lactose. At nine weeks of age the calves were able to utilize maltose. The results of this study indicate, that in the young calf, amylase and maltase activity is very low, and lactase activity very high. Huber et al. (1961), using calves 22 to 600 days old, introduced slurries of glucose, lactose, maltose, sucrose, amylose, amylopectin, flojel (acid treated starch), and tapioca starch orally. Starch, maltose, and sucrose were poorly utilized in contrast to glucose and lactose that were well utilized in the small intestine. Lactose utilization decreased markedly with age. Maltase levels increased up to 6 to 8 weeks of age. Blood sugar responses to treatment were twice as great at 6 to 8 weeks of age than at 2 to 4 weeks of age. Walker (1959) found little amylase activity and no sucrase activity in

young lambs. However, amylase activity was found to increase with age.

Henschel et al. (1963) gave 10 g. each of several carbohydrate treatments to 4 to 6 month old calves. The carbohydrates administered were: raw wheat starch, maltose, lactose, sucrose and glucose. Only two percent and 14 percent of the glucose and lactose respectively were recovered at the proximal end of re-entrant intestinal cannulas. As much as 60 percent of the raw wheat starch and 62 percent of the sucrose were recovered. With the addition of amyloglucosidase to the starch treatments, only seven percent of the raw wheat starch was recovered. Larsen et al. (1956) also found a limited ability of calves to utilize corn starch post-ruminally and noted very limited amylase activity in this area. Siddons (1968) noted that in young calves amylase activity increased with age and reached a maximum at 101 days of age. Maltase activity was found to be independent of age and quite similar between the adult and calf.

Cereal Grain Starch in Ruminant Rations

The primary cereal grains fed to ruminants in the United States are: corn, barley, sorghum, wheat, and oats. Starch present in each cereal grain expressed as a percentage of dry matter is as follows: corn, dent, yellow, all analysis, 71.3 percent; barley, all analysis, 63 percent; sorghum, all analysis, 70 percent; wheat, all analysis, 63 percent; oats, all analysis, 50 percent. Corn and

sorghum account for about 80 percent of the starch from concentrates fed to ruminants with slightly more than 35 million metric tons of starch consumed by domestic animals in the United States in 1970 (Waldo, 1973). Eighty-three percent of this starch was consumed by cattle on feed (54 percent) and milk cows (29 percent).

In plants, starch exists as granules in cells known as plastids (Banks and Greenwood, 1975). French (1973) described these discrete water insoluble starch particles or granules as being from 1 μm to well over 100 μm in diameter. Gray (1970) indicated that starch existed in these granules in two molecular forms, that of amylose and amylopectin. Approximately 20 percent of cereal grain starch is amylose and 80 percent amylopectin. Amylose is a homogenuous, polymerized molecule consisting of D-glucose units linked via alpha 1-4 glycosidic bonds (French, 1973). Each molecule will be comprised of approximately 1000 D-glucose residues and prefers a coiled helix confirmation with 6 glucose residues per turn (Everett and Foster, 1959; Metzler, 1972). Amylopectin is a highly branched molecule consisting of 1000 to 500,000 D-glucose residues. Amylopectin is similar to amylose in that the vast majority of the glucose residues are linked to each other via alpha 1-4 bonds. However, in amylopectin branch points or chains will occur linked by alpha 1-6 glycosidic bonds. These chains will occur every 25 to 30 glucose units, and consist of 20 to 25 glucose molecules. The alpha 1-6 linkages will

comprise up to 4 to 5 percent of the total linkages present in amylopectin (Oser, 1965).

The majority of ingested starch is fermented in the rumen by anaerobic micro-organisms to steam volatile fatty acids. Microbial fermentation can also take place in the ceacum and colon of the lower gut. In either case, these acids are absorbed through the gut wall into the portal blood stream and utilized in the liver as an energy or carbon source (Baldwin, 1965). Propionic acid serves as the principal source of glucose for the ruminant but acetic and butyric are considered ketogenic (Topps et al., 1968).

The means by which ration starch is utilized as an energy source depends on where digestion takes place. Significant amounts of starch will also undergo enzymatic degradation to glucose in the small intestine in a manner similar to that of the monogastric animal. The end result is the uptake of glucose in the small intestine (McDonald, 1969). In this digestion, the inefficiencies of fermentation resulting from heat, carbon dioxide and methane production are not present (Armstrong et al., 1960).

Site and Extent of Starch Digestion in the Ruminant Digestive Tract

It has become increasingly apparent that the lower gut (small intestine, ceacum and colon) makes a significant contribution to the

nutritional well being of the ruminant (Noller, 1978). Henschel et al. (1963) concluded through studies with young steers there was extensive carbohydrate digestion occurring post-ruminally due to digestive enzyme action and bacterial fermentation. McCullough (1973) speculated that the gain and feed efficiency advantage of whole corn versus flaked corn diets was due to an increased rumen by-pass of whole corn to the small intestines. McCullough's speculation was based upon his review of several experiment station research trials. Poutiainen et al. (1971) when feeding young steers a mixed diet of barley and grass hay versus grass hay only, thought it interesting that 14 percent more of the mixed diet was digested in the ceacum, and resulted in a 12 percent greater carcass weight gain.

The site of starch degradation in the gastro-intestinal tract appears to be influenced by four factors. These factors are as follows: 1) the level or proportion of grain to roughage in the ration, 2) the level of intake, 3) the type of grain processing and 4) the type of cereal grain fed.

The Influence of the Grain to Roughage Ratio

In general, as the proportion of grain to roughage in a ration increases greater quantities of starch escape rumen fermentation. Zinn and Owens (1980a) fed a 40 percent hay, 60 percent rolled corn

diet to steers fitted with dual re-entrant cannulas in the small intestine. The workers found 443 g. of starch escaping rumen fermentation from this diet. When the hay was reduced to 20 percent of the ration, and the corn increased to 80 percent, undigested starch leaving the abomasum more than doubled to 956 grams. Poutianen et al. (1971) found similar results with young calves. In this study the amount of dry matter escaping rumen fermentation increased 14 percent when 50 percent barley was included in a previously all dried hay diet. Macrae and Armstrong (1969) found that an increase of rolled barley from 33 to 66 percent in rations fed sheep increased the starch escaping to the proximal duodenum from 17.5 to 26.5 grams per 24 hours. Topps et al. (1968) fed either all hay or hay plus 298 g. of starch to sheep in order to evaluate the influence of the presence of concentrate on digestible energy disappearance in the gastro-intestinal tract. There was nine percent less digestible energy disappearing in the reticulo-rumen, omasum, and abomasum, and 16 percent more digestible energy disappearing in the small intestine in the hay plus starch diet than the all hay diet. Tucker et al. (1968) found as much as 35 percent of dietary starch escaped rumen fermentation in four wethers fed diets ranging from 20 to 80 percent corn. These workers noted that post-ruminal digestion of starch was very efficient with only 20 to 26 g. of starch appearing in the feces regardless of the level of corn in

the diet. Karr et al. (1966) fed yearling Angus steers rations consisting of 19 to 35 percent starch, and found that 16 to 38 percent of the starch escaped rumen fermentation. It was noted in this study that as starch intake increased digestibility decreased in the small intestine, and increased in the large intestine. Teeter et al. (1980) found that with 554 kg. Angus steers fed whole corn no roughage diets significant amounts of starch escaped rumen, and post-ruminal digestion, and appeared in the feces. The amount of undigested starch present in the feces was reduced 85 percent when 40 percent roughage was added to the ration in the form of cottonseed hulls or alfalfa hay.

In contrast, other workers have shown forage level in the ration to have little effect on the extent of ruminal bypass of starch. Topps et al. (1969) fed diets of increasing starch content to steers and found the amount of starch reaching the abomasum undigested varied little among diets. It should be noted that ration intake was restricted in this study which has been shown to limit the bypass of starch from the rumen (Wheeler et al. 1975). Nicholson and Sutton (1969) fed diets with either 80:20 or 25:75 ratios of concentrate to roughage to sheep. The diets with the highest proportion of concentrate showed only a slight increase in the amount of undigested starch reaching the duodenum. All but 5 to 11 percent of the starch was fermented in the rumen. However, there is evidence rumen

fermentation in sheep is more extensive than cattle (Armstrong and Beever, 1969).

The Influence of the Level of Ration Intake

Although with high grain rations, substantial amounts of ration starch escape rumen degradation, most of the work cited in the preceding section indicate total tract starch digestion is complete and efficient. Most of the previously cited studies report total tract digestibilities of starch at 90 to 100 percent, with little or no loss of starch in the feces (Waldo, 1973). However, Wheeler (1980a) indicated that the majority of these trials were done with animals fed at or near maintenance levels of ration intake. Therefore, in many trials, stresses are not placed on the ruminant similar to those found when full feeding high concentrate rations.

Karr et al. (1966) noted that total tract digestion of ration starch was from 97 to 99 percent regardless of the level of starch in the ration. In these trials, only 12 to 62 g. of starch appeared in the feces. Tucker et al. (1968) noted total tract digestibility of starch was from 94.5 to 98.4 percent. Orskov et al. (1969), in trials conducted using different forms of corn or barley fed to sheep, noted a mean of only one percent of ration starch appearing in the feces, and total tract digestion of starch from 99.2 to 99.3 percent. It should be noted that in one lamb, 25 percent of the

dietary starch escaped rumen fermentation in this study.

Wheeler et al. (1975) fed rations of forage-concentrate ratios of 75:25, 60:40, 45:55, and 30:70 to Holstein cows. When these rations were fed at maintenance levels of intake, starch digestibility averaged 96.2 to 96.8 percent. Starch appearing in the feces at this level of intake was only 5 percent of the fecal dry matter. When the rations were fed at 2.3 to 3.2 times maintenance level of intake, starch digestibility decreased and ranged from 84.7 to 88.1 percent. The percentage of starch appearing in the feces increased to 13.4 percent of the fecal dry matter. Wheeler et al. (1976) again fed high concentrate diets ad libitum to lactating dairy cows and noted that the percent of fecal starch ranged from 19.0 percent for barley rations up to 40.0 percent for corn based diets. In another study with crossbred steers fed ad libitum a high moisture corn and silage ration, Wheeler and Noller (1976b) found the percent of starch in the fecal dry matter as high as 32.4 percent.

Zinn and Owens (1980a) fed a 20 percent roughage, 80 percent rolled corn diet to Angus steers at two levels of intake. At an intake of 1.5 percent of body weight/day, 338 g. of ration starch was presented to the small intestine. Increasing the intake to 2.0 percent of the steers bodyweight/day increased the amount of starch presented to the small intestine to 956 g./day. Watson et al. (1972b) fed what were considered a low level (5.08 kg. dry matter/24 hr.) and

a high level (8.6 kg. dry matter/24 hr.) of rolled barley rations to mature cows. In the low level diet, 91.4 percent of the ration starch was digested before the duodenum, and 9.0 percent in the small intestine. The workers indicated an appreciable amount of dietary starch escaped rumen fermentation with the high level of intake, 75.8 percent of which was digested in the small intestine, 22.5 percent fermented in the ceacum, and only 1.7 percent appeared in the feces.

Orskov et al. (1969) found that when intake of rolled barley or rolled barley plus grass hay diets was decreased from ad libitum to 70 percent of ad libitum intake, the amount of starch escaping the rumen undigested decreased an average of 38 percent. Little et al. (1968) infused 200, 400, and 600 g. of starch into the abomasum of steers twice daily in order to estimate the digestion of starch in high concentrate rations. The workers found that as the level of ration starch increased the digestibility of starch in the small intestine decreased, with greater quantities being recovered in the posterior ileum and the feces.

Nicholson and Sutton (1969) fed .9, 1.7 and 2.3 multiples of maintenance intake of high grain rations to sheep. In this study, all but 5 to 11 percent of the ration starch was fermented in the rumen regardless of the level of intake. As mentioned earlier, this may be due to the species used since rumen digestion in sheep is

apparently more extensive than in cattle (Armstrong and Beever, 1969).

The Influence of Grain Processing

Various methods of processing cereal grains for livestock has continued to improve the palatibility or the utilization of grains. There are at least eighteen different means of processing grain, including grinding, steam rolling, pelleting, flaking or dry rolling (Hale, 1973).

Grains that have undergone extensive processing will be digested more thoroughly in the rumen (McCullough, 1973). McNeill et al. (1971) evaluated the digestibility of sorghum grain processed by four different methods. The sorghum grain was either dry ground, steam flaked, reconstituted whole kernel and ground prior to feeding or micronized. Ruminal starch digestion was greatest for steam-flaked sorghum and least for the dry ground form.

Galyean et al. (1976) compared the digestibilities of four processed forms of corn. Evaluated were dry rolled, steam flaked, ground ensiled high moisture corn, and acid-treated high moisture whole corn. The workers found that the ground high moisture, and steam flaked corn had greater total tract digestibility reflecting greater degradation in the rumen. There was no difference in the digestibility of starch in the small intestine among any of the different methods of processing.

Beever et al. (1970) fed diets of four parts corn and one part dried grass to sheep. The corn was either ground or steam flaked. Starch digestion in the rumen was 95.6 percent for the steam-flaked corn and only 77.7 percent for the ground corn. When the steam flaked form was fed, only .8 g./24 hr. of starch appeared in the feces. Total tract digestibility of starch was still 99.6 and 99.9 percent for the ground and steam flaked forms respectively, despite 22 percent of the starch passing the rumen undigested from the ground corn diet. McCullough (1973) fed either flaked corn or whole corn to yearling steers and found rumen, small intestine, ceacum and colon and total tract starch digestibility of 91.1 percent, 7.9 percent, 0.9 percent, and 97.6 percent for the flaked corn diet and 61.1 percent, 34.0 percent, 2.5 percent and 99.8 percent for the whole corn ration.

Macrae and Armstrong (1969) found that, in trials with sheep, more undigested whole barley versus rolled barley appeared in the feces. Orskov and Fraser (1972) noted that rumen breakdown of pelleted barley was greater than whole barley in sheep feeding trials. MacLeod et al. (1972), in studies with growing steers, found that when whole barley diets were fed, there was a 10 percent reduction in dry matter and nitrogen digestibility when compared to the digestibility of rolled barley. Orskov et al. (1969) fed either flaked corn, ground corn, or cracked corn to sheep and found that undigested starch reaching the abomasum was twice as great for the

lambs fed ground or cracked corn as for those fed the flaked-corn diets.

The Influence of the Type of Cereal Grain Fed

Waldo (1973) indicated corn, sorghum, wheat, oats, and barley as the most commonly used cereal grains. The location and extent of starch digestion will also depend in part on the type of grain used in the ration.

Kay et al. (1972) fed pelleted diets of either whole wheat, whole corn, whole barley or whole oats to 100 to 400 kg. Holstein steers. The amount (g./day and percent of intake) of undigested starch passing the abomasum was: 395 g. (17 percent), 1008 g. (40 percent), 398 g. (19 percent) and 417 g. (27 percent) for the wheat, corn, barley and oats diets respectively.

Barley is more extensively degraded in the rumen than is corn. Watson et al. (1972a) fed rolled barley or ground and pelleted corn to mature cows. The barley and corn rations contained an average of 73.0 percent and 74.8 percent apparent digestible energy. The percentage of apparent digestible energy disappearing before the duodenum, in the small intestine and the ceacum and colon was 65.0 percent, 23.0 percent and 13.6 percent, respectively for the barley ration. Corresponding values for the corn diets were 54.4 percent, 34.7 percent and 12.0 percent. Orskov et al. (1971a) fed diets

consisting of rolled barley and various protein levels to sheep fitted with abomasal and ileal cannulas. The workers noted that even when fed at near ad libitum intake, 93 percent of the barley starch was digested in the rumen. Orskov et al. (1971b) studied various rumen characteristics associated with barley or corn diets fed to sheep. The rumen fermentation values for the barley and corn were 91.0 percent and 78.0 percent, respectively. The amount of corn digested in the small intestine varied from 2 to 37 percent of the ration intake. When large quantities of starch escaped rumen fermentation, an average of 6 percent of ingested starch was fermented in the large intestine, and up to 2.0 percent appeared in the feces. These fermentation values are in close agreement with Waldo (1973), who indicated barley, flaked corn, steam flaked sorghum, wheat and oat starches were about 94 percent fermented in the rumen. Ground corn starch was said to be about 74 percent fermented in the rumen.

Tyrrell et al. (1972) compared barley and corn for efficiency of fattening 416 kg. yearling heifers. The workers found little difference in energy utilization between barley and corn. Metabolizable energy for corn was used with 53.2 percent efficiency and for barley 47.5 percent efficiency. It was noted that as intake increased for both barley and corn, available metabolizable energy decreased.

Sorghum starch is said to be the cereal grain starch most resistant to rumen digestion. The extent of rumen degradation will

be influenced by endosperm types of sorghum. This factor is exemplified by the following endosperm types for sorghum and their associated rumen fermentation values: corneous, 48 percent; normal, 18 percent; waxy, 75 percent; and floury, 80 percent (Waldo, 1973). McGinty and Riggs (1968) studied the digestion co-efficients of eight different varieties of sorghum grain when fed to steers. The co-efficients of digestion ranged from 50.0 percent to 71.58 percent. McNeill et al. (1971) fed dry-ground, steam-flaked, reconstituted or micronized forms of sorghum grain as four treatments to Angus steers. They found rumen fermentation values varied greatly according to type of processing. These values were 42.25 percent, 66.28 percent, 82.23 percent, and 43.38 percent for the dry ground, steam flaked, reconstituted and micronized forms, respectively. There was no difference noted in total tract digestibility of starch. Holmes et al. (1970) fed steamed or pressure steamed sorghum grain to sheep and cattle. Both the steamed and pressure steamed forms of the sorghum had rumen fermentation values of 90 and 95 percent respectively and total tract digestibility of 97 percent.

The extent of ruminal starch digestion for wheat starch is thought to be similar for barley. Oat starch is also thought to be readily attacked in the rumen (Waldo, 1973).

Digestive Irregularities and High Grain Diets

Digestive irregularities are often associated with high intakes of high-grain, low-roughage rations. These digestive anomalies include: 1) the development of acidic conditions in the reticulorumen small and large intestine, 2) a marked reduction in the production of alkaline, buffering saliva, 3) an accelerated rate of passage through the digestive tract at high intakes, and 4) a possible decrease in the activity of pancreatic alpha amylase resulting in poor hydrolysis of undigested starch presented to the small intestine (Noller, 1978). Wheeler (1980a) indicated the major digestive anomaly is the development of acidic conditions in the digestive tract. The acidic condition in combination with the other digestive disorders cause an unfavorable environment to exist in the gastro-intestinal tract for the optimum utilization of nutrients.

Reticulorumen pH

The pH of the reticulorumen area is the result of volatile fatty acid (VFA) production and absorption, level of feed intake, and saliva production (Wheeler, 1980a). Reticulorumen pH is maintained within the pH 5.5 to 7.3 range. Values associated with the lower end of this range (pH 6.0 and below) often accompany reduced feed intake, reduced reticulorumen motility, and impaired fermentative capabilities for the rumen micro-organisms (Trenkle, 1979). Protozoal populations are lost or greatly diminished as pH

drops. Hungate (1966) found protozoa were unable to survive at pH 5.5. Reduced pH conditions in the reticulorumen often precede the the production of lactic acid (pKa 3.8) from increased numbers of Streptococcus and Lactobacillus organisms. The production of large amounts of lactic acid often results in sudden death syndrome or lactic acidosis in feedlot cattle (Uhart and Carroll, 1967).

Reticulorumen Buffer Systems

The ruminant must possess a means of maintaining a pH environment conducive to microbial growth because large amounts of volatile fatty acids are produced which are found to yield pH values of 2.78 to 3.03. Three major systems the ruminant utilizes to buffer this acidity include the following: 1) the exchange of bicarbonate across the rumen wall, 2) the blood buffer system, and 3) the salivary buffer system (Bartley, 1975).

Kay and Hobson (1963) described the initial step of the bicarbonate exchange system in the reticulorumen as the diffusion of carbon dioxide (CO_2) across the rumen wall. Carbonic anhydrase, an enzyme abundant in animal tissue, would catalyze the hydration of CO_2 to carbonic acid (H_2CO_3) (Metzler, 1977). Carbonic acid is a weak acid and would dissociate into the bicarbonate (HCO_3^-) and hydrogen ion (H^+) in the following manner:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-.$$

The result of the dissociation of carbonic acid is the establishment

of a conjugate acid-base system between carbonic acid and the bicarbonate ion (Trenkle, 1979).

The blood buffering system is present in the plasma and erythrocytes, and maintains blood pH at pH 7.4 despite the absorption of substantial amounts of volatile fatty acids from the reticulorumen. Erythrocytes such as hemoglobin make use of the bicarbonate buffer system, and the imidazolium group of the amino acid histidine as proton acceptors. Blood plasma will make use of the phosphate buffer system ($H_2PO_4^-$ / HPO_4 = pKa 7.2) but obtains 75 percent of its buffering capabilities from the bicarbonate system (Trenkle, 1979).

Kay and Hobson (1963) described the role of the salivary buffer system as being a first-line defense against acidity in the reticulorumen from the production of organic acids. McManus (1959) diverted saliva from the reticulorumen of sheep and noted VFA levels rose from 60 to 115 molar equivalents / liter of rumen fluid. The pH of the reticulorumen environment decreased from 6.7 to 6.2 after the saliva was diverted. When saliva was not diverted, VFA levels decreased approximately 30 molar equivalents and the pH increased slightly. Similar effects were shown in later work by McManus (1962) when saliva was prevented from entering the reticulorumen of sheep that were fitted with esophageal cannulas.

Saliva is a mixture of secretions originating from the parotid, submaxillary, buccal, inferior molar, sublingual and labial glands

(Trenkle, 1979). Saliva is strongly alkaline with a pH of 8.1 because the secretions of the parotid inferior molar, and buccal glands are strongly buffered with bicarbonate and phosphate (Bartley, 1975). The bicarbonate buffer system is the primary means used in saliva to buffer reticulorumen acidity. Saliva is most effective as a buffer in the pH range of pH 6 to 7 (Trenkle, 1975).

Reticulorumen Acidity and Volatile Fatty Acid Production

The volatile fatty acids are produced in the reticulorumen in sufficient quantities to provide 60 to 80 percent of the metabolizable energy required by the ruminant (Thorlacius and Lodge, 1973). Organic acids produced in such quantities would have a marked effect on reticulorumen acidity unless they are sufficiently absorbed or neutralized (Trenkle, 1979). Briggs et al. (1957), in studies with rumen fistulated sheep, found an inverse relationship existed between volatile fatty acid levels and reticulorumen pH. Balch and Rowland (1957) also found an inverse relationship existed between volatile fatty acid levels and reticulorumen pH in their studies with Shorthorn cows.

The reticulorumen concentration of volatile fatty acids is in the range of 60 to 120 millimoles / liter of rumen fluid. The concentration of volatile fatty acids in the reticulorumen can reach a maximum of 200 millimoles / liter of rumen fluid, especially

when high concentrate finishing rations are fed. Passive uptake of volatile fatty acids occurs across the squamous, stratified, reticulorumen epithelium. The diffusion of volatile fatty acids across the reticulorumen wall is dependent on their concentration in the blood (Trenkle, 1979). The reticulorumen epithelium is more permeable to the unionized than the ionized form of the volatile fatty acids. The pKa of the VFA is low (2.7 to 3.03); therefore, absorption will tend to increase as reticulorumen pH decreases (Thorlacius and Lodge, 1973). Sutton et al. (1963) using rumen fistulated calves, 16 to 21 weeks of age, studied the absorption of VFA across the reticulorumen wall at different pH levels. Phosphoric acid or sodium hydroxide was used to adjust the reticulorumen pH environment. Absorption at pH 5.0 was more than double the rate of absorption at pH 6.6 and four times the rate of absorption at pH 8.0. These findings suggest that as pH in the reticulorumen decreases, blood VFA levels could increase to a point where absorption would be hindered because of rapidly increasing concentrations in the blood.

High-grain diets are readily fermented in the reticulorumen, resulting in the rapid production of volatile fatty acids. The relationship between ration characteristics and reticulorumen VFA levels is aptly described in the following quote by Church (1969), "However, it is probably safe to conclude that the ingestion of

immature grass, increasing amounts of carbonaceous or protein supplements, increasing levels of feed intake, and pelleted roughages tend to result in higher VFA levels." Phillipson and McAnally (1942) demonstrated the differences in the effect of roughage versus concentrate on reticulorumen pH and VFA levels when 100 g. of starch or cellulose were infused into the reticulorumen of sheep. The infused corn starch caused a prolonged decrease in reticulorumen pH and a steady sustained rise in the VFA levels. The cellulose infusion caused no such effect on pH or VFA levels. Kern et al. (1974) demonstrated that near neutral conditions (pH 6.9) existed in the reticulorumen of steers fed an all roughage diet consisting of timothy hay. Luther and Trenkle (1967) fed all-roughage rations to lambs and noted a pH of 6.5 in the reticulorumen. These workers added 40 percent concentrate to the diet and noted that pH levels in the reticulorumen decreased to pH 6.2.

Diets consisting of part grain or all grain will usually result in increased VFA levels and decreased pH in the reticulorumen. Briggs et al. (1957) used rumen fistulated sheep to demonstrate the effect of including grain in a ration on reticulorumen pH and VFA levels. The sheep first received an all roughage ration which caused reticulorumen VFA levels to increase to a maximum of 104 millimoles / liter of rumen fluid and pH level to decrease to 5.85. The sheep were then adapted to a high grain diet

(70 percent wheat grain, 30 percent roughage, and 85 g. of starch) which caused reticulorumen VFA levels to rise to a maximum of 153 millimoles / liter of rumen fluid and pH to drop as low as 4.5. Phillipson (1942) found results similar to Briggs' results after feeding four types of rations to rumen fistulated sheep. The diets were composed of the following: oats and bran; pasture grass; grass hay; or mangold and cabbage. The mangold and cabbage diet was considered a high-concentrate diet high in reticulorumen soluble carbohydrates such as starch. The mangold and cabbage diet caused a rapid fall in reticulorumen pH accompanied by increased VFA levels.

Work by Thompson et al. (1967) suggests ration particle size will influence reticulorumen pH and VFA levels. The workers fed Angus steers ground or flaked corn with no hay, or with 1.8 kg/day of either chopped or long hay. Steers fed corn and long hay had significantly higher rumen pH values (pH 6.3) and lower VFA levels (126.5 millimoles / liter of rumen fluid) than steers fed the corn plus ground hay diet (pH 5.9 and VFA level of 155.7 millimoles / liter of rumen fluid). Shaw et al. (1960) fed two groups of eight Holstein steers ground corn with coarsely chopped alfalfa hay (diet 1) or flaked corn fed with finely ground alfalfa hay (diet 2). Diet 2 caused a twofold increase in reticulorumen VFA levels (1357.4 mg./ 100 ml. rumen fluid) over diet 1 (580.4 mg./100 ml. rumen fluid). Reticulorumen pH was not measured in this study. Rhodes and Woods

(1962) fed long stem alfalfa hay to sheep and noted a reticulorumen pH level of 6.1. The same type hay was subsequently finely ground and pelleted, with ground corn added to the diet. The pelleted hay and corn diet caused rumen pH to decrease to 5.8. There was little difference in total VFA levels between the hay and pelleted hay and corn diet, but the molar percent propionic acid did increase when the hay and corn ration was fed. Noller (1980) would interpret the difference in reticulorumen pH between the diets to the greater production of propionic acid which is often associated with reduced pH in the reticulorumen. Esdale and Satter (1972) decreased the reticulorumen pH of Holstein cows from 6.2 to 5.6 and found the molar percentage of propionic acid to increase from 19.8 to 37.2 percent. The molar percent of acetic acid decreased from 68.5 to 43.0 percent. Bailey (1961) would indicate the effect of ration particle size on reticulorumen pH and VFA production to be due to a decrease in saliva production and reduced buffering characteristics in the reticulorumen.

The level of ration intake also influences reticulorumen pH and VFA production. Rumsey et al. (1970) fed steers all concentrate diets consisting of cracked corn. The levels of ration intake were at .5, 1.0, 1.5, and 2.0 percent of steer bodyweight per day. Reticulorumen pH and VFA levels (millimoles / liter of rumen fluid) for each increasing level of intake were as follows: 6.2, 115.9;

6.2, 136.6; 5.9, 163.2; and 5.7, 183.9. Bath and Rook (1963) increased the intake of all roughage rations fed to cows from 4.5 to 9.1 kg./hd./day. The higher level of intake caused reticulorumen VFA levels to increase from 7.4 to 10.5 molar equivalents / 100 ml. or rumen fluid. Reticulorumen pH decreased from 6.65 to 6.3 as intake increased to 2.0 percent of bodyweight.

Acidity in the Lower Gastro-intestinal Tract

The pH environment of the lower gastro-intestinal tract of the ruminant was thought to be of little consequence to its nutritional well being (Noller, 1978). However, Harrison and Hill (1962) noted in their studies with sheep that the duodenum is a highly acidic environment which is poorly buffered by pyloric, duodenal, and pancreatic secretions. The workers concluded that enzyme activity in the small intestine would be limited due to the acidic conditions. Wheeler and Noller (1977) indicated the desirable pH of the small intestine to be from pH 6.5 to 7.0. This pH range theoretically would allow for the optimum activity of pancreatic alpha amylase and the efficient degradation of starch bypassing the reticulorumen undigested. These workers demonstrated in slaughter studies with cattle and sheep that acidic conditions prevail not only in the reticulorumen but also in the small and large intestine in ruminants fed high grain rations, and that little change in pH occurs through

the lower tract to the feces. In one trial, Holstein steers were fed all-concentrate diets, ad libitum, consisting of either rolled barley, whole kernal corn, or cracked corn. The pH of the reticulorumen (RR), small intestine (SI), colon (C), and feces (F) for each of the three respective diets were as follows: RR: 5.84, 5.64, 5.38; SI: 6.18, 5.75, 5.75; C 6.17, 5.93, 5.82; F: 6.11, 5.93, 6.00. Wheeler et al (1976) fed eight crossbred ram lambs a pelleted, 80 percent corn grain diet for 84 days. The lambs were evenly divided into two groups with one group fed ad libitum, and the second group fed at maintainence intake of digestible energy. The pH levels of the small intestine for both the ad libitum and maintainence intake groups were 6.16 and 6.25. Wheeler and Noller (1977) found there was no significant difference ($P > .10$) between the pH of the small intestine and the feces in their studies. They concluded that the pH of a fecal grab sample was an excellent indicator of pH in the small intestine. Ferreira et al. (1980) also found no significant difference between fecal pH and small intestinal pH in their studies with Holstein heifers and calves.

Kern et al. (1974) demonstrated that near neutral conditions not only prevail in the reticulorumen, but also in the small and large intestine of steers fed all timothy hay diets at two percent of bodyweight per day for 30 days. The pH of the reticulorumen (RR), small intestine (SI), Cecum (CE), and terminal colon (TC) were the

following : RR: 6.0; SI: 7.3; CE: 7.0; TC: 7.2. Armstrong and Beever (1969) noted that the pH in the jejunum of sheep fed grass hay cubes ranged from pH 7.2 to 7.9. Ben Ghedalia et al. (1974) added 600 g. of concentrate to a vetch hay diet fed to sheep and noted the pH did not increase to 7.7 until the terminal ileum.

Digestion in nonruminants such as humans takes place primarily by enzyme catalysis in the small intestine. The acidity arising from the acid secretions of the stomach is effectively buffered by pancreatic and intestinal secretions. Borgstrom et al. (1957) noted with humans that the pH of the stomach ranged from 2.5 to 3.0, but increased immediately in the duodenum to 6.0. Kay (1969) demonstrated the ruminant does not have the same buffering capabilities in the small intestine as the nonruminant. In his studies with sheep, Kay noted the secretions from the duodenum and jejunum were weakly alkaline and contained very little bicarbonate. The pH in the intestine of these sheep was found to increase gradually from 2.4, .05 meter from the pylorus to 5.2, 2 meter beyond the pylorus to 7.8, .3 meter before the ceacum.

Copious and continuous influxes of acid chyme from the reticulorumen and abomasum combined with the weakly alkaline nature of the secretions entering the small intestine produce the lower pH often existing in the small intestine (Noller, 1978). The abomasum is comparable to the simple stomach in nonruminants, with the pH

remaining close to 3 (Phillipson, 1977). The acid chyme leaving the abomasum is a continuous process and is only partially neutralized in the small intestine (Harrison and Hill, 1962). The secretion of hydrochloric acid from the abomasum was found to increase as intake increased in studies with sheep by Ash (1961). Using an inervated fundic pouch of the abomasum, the workers measured the secretion of hydrochloric acid. Increasing the intake of a dried grass hay diet from 700 g. to 1100 g. per day increased the secretion of hydrochloric acid from 15 to 45 molar equivalents per 24 hours. The increased ration intake also increased the rate of passage of acid chyme from the abomasum from 130 to 250 milliliters / 30 minutes, with a maximum outflow of 934 milliliters / hour. Harrison and Hill (1962) noted the rate of passage of material through the duodenum of sheep increased from 13.3 to 26.0 milliliters per hour when feeding was increased from once per day to three times per day. The workers did not state whether or not the amount of ration was also increased. The preceding work suggests the common practice of full feeding rations to ruminants would increase the rate of digesta passage and the secretion of hydrochloric acid from the abomasum to the small intestine.

Impaired Saliva Production

Normally, large quantities of saliva are produced by ruminants

daily. Putnam et al. (1966a) found the production of saliva in 350 kg. beef steers varied from 33.5 to 54.1 liters per day. Bailey (1961) collected and dried boluses from the reticulorumen and estimated the daily saliva output of a mature cow to range from 98 to 190 liters per day. Kay (1959) estimated sheep will secrete from 6 to 16 liters of mixed saliva per day.

The accepted practice of feeding processed high-energy, low-fiber rations to ruminants often results in a marked reduction in salivary secretion and reticulorumen pH (Emmanuel, 1968). This reduction in saliva production is due primarily to decreased time spent chewing or ruminating (Bartley, 1975). Putnam et al. (1966b) fed four steers (average weight 400 kg.) a ration consisting of 89 percent hay at 1.5 percent of bodyweight daily intake. The hay was coarsely ground, or finely ground (10 millimeter screen) and pelleted. Saliva secretion decreased from 2.0 to 1.4 liters / hr., and reticulorumen pH decreased significantly ($P < .10$) when the steers were fed the pelleted hay. The workers also demonstrated the effect of roughage level on saliva production and reticulorumen pH. The hay was reduced to 25.0 percent of the ration with 63.0 percent cracked corn added to the diet. Saliva secretion decreased from 2.0 liters / day for the all roughage ground hay diet to 1.5 liters/ day for hay diet which included grain. The pH of the reticulorumen also decreased from pH 6.7 to 6.3. Baily (1961) also found that

as the amount of concentrate in the diet increased the amount of saliva secreted decreased. In his study, cows of unspecified breed or weight were fed a diet of 6.4 kg. of medium quality hay or .9 kg. of hay and 5.4 kg. of flaked corn daily. The daily saliva secretion decreased from 149 to 128 liters when the all-hay diet was replaced with diet that included the flaked corn. Balch (1958) fed either concentrates or hay to Shorthorn cows and Holstein steers. The cows and steers secreted an average of 24.4 kg. of saliva / kg. of dry matter consumed from the all-hay diet. The diets were switched to the one containing flaked corn, and saliva production was reduced to 16.1 kg./kg. of dry matter consumed. Jaw movements of the cattle consuming the flaked corn diet were noted by the workers to be less pronounced than those consuming the all hay diet. Yarns et al. (1965) fed Angus, Shorthorn and Hereford steers (average weight 305 kg.) rations of 50 percent bermuda grass and 50 percent cracked corn or 100 percent finely ground and pelleted alfalfa hay. Saliva was collected every 15 minutes after feeding by an esophageal cannula which prevented the entry of saliva into the rumen. Average daily saliva secretion decreased from 56.6 to 41.8 liters/day when the finely ground alfafla hay diet was substituted for the bermuda grass and cracked corn diet. The workers concluded the finely-ground, alfalfa hay diet was of a less fibrous nature than the bermuda grass and corn diet and was consumed more rapidly resulting in less saliva

production. Baily and Balch (1961) fed Shorthorn cows four diets consisting of the following: 18 kg. of lucerne silage or 6.5 kg. of medium quality hay, 4 kg. of hay and 5.4 kg. of dairy cubes; 5.4 kg. of flaked corn and .9 kg. of ground nut cake and .9 kg. of hay, or a freshly cut mixture of ryegrass. The amount of saliva secreted was greatest for the grass hay diet and least for the lucerne silage diets. Meyer et al. (1964) would attribute the reduction of saliva production to a reduced dry-matter intake from the silage versus the dried grass hay diet. These workers used Holstein cows fed either freshly cut alfalfa or mature hay and noted saliva secretion decreased from 15.8 to 8.0 kg. per feeding when the freshly cut succulent alfafla was substituted for the mature hay diet.

Wilson and Tribe (1963) noted secretion from the parotid gland decreased from 1.95 to .32 liters per day when meadow hay was fed in a finely-ground versus a coarsely chopped form. The workers used Merino wethers in which the left parotid duct was transplanted to the cheek. A polyvinyl tube attached to the parotid fistula allowed the saliva to drip from the tubing into a plastic bottle.

Increased Rate of Passage With Finishing Rations

Miller et al. (1971) used 120 kg. calves of dairy-beef breeding to study the movement of food material through the digestive tract

in relation to time. In this study the calves were fed alfalfa-mixed hay ad libitum with 2 kg. of concentrate per head per day. Radiocerium (either ^{141}Ce or ^{144}Ce) was used as the nonabsorbed marker to follow food material through the digestive tract. In an earlier study Miller et al. (1969) found this isotope will absorb onto undigested food material and move with that material through the gastrointestinal tract. Groups of 4 to 6 calves were given oral doses of the isotope at 4 hour intervals from 4 to 72 hours before slaughter. At the time of slaughter the digestive tracts of the calves were removed and sectioned to determine the amount of isotope present. The workers found that cerium in the rumen decreased from 80 percent of the total recovered from the entire digestive tract and feces at 4 hours to 6 percent of the total recovered at 72 hours after dosing. Cerium in the abomasum decreased from 2 percent of the total recovered at 4 hours to .2 percent at 72 hours after dosing. In the small intestine cerium decreased from a peak of 6 percent of the total recovered between 8 and 12 hours and decreased to .7 percent by 72 hours after dosing. Cerium in the large intestine peaked at 20 percent of the total recovered by 20 hours after dosing. Cerium did not appear in measurable amounts in the feces until 8 hours after dosing.

The rate of passage of digesta through the digestive tract often increases when high grain diets are fed, resulting in decreased

ration digestibility. Mumford (1928) studied ration digestibility and rate of passage using four steers. He concluded from his study that ration digestibility would be greater if passage through the digestive tract is slow, allowing more time for digestive enzyme action. Noller (1978) indicated digestibility of high grain rations is reduced in part because of an increased rate of passage through the digestive tract at high ration intakes. Anderson et al. (1959) found ration digestibility to decrease as intake increased. In their study 18 to 36 month old Holstein steers were fed rations of either 40:60 or 20:80 ratios of forage to concentrate. The rations were then fed at 1.1 to 3.1 times maintainence intake. Dry matter digestibility of the 40:60 forage to concentrate ration decreased from 85.7 percent at .5 time maintenance intake to 74.3 percent at 2.7 times maintenance intake. Dry matter digestibility of the 20:80 forage to concentrate ration decreased from 78.0 to 69.0 percent when intake was increased from 1.0 to 2.0 times maintenance intake. The workers concluded animals derive 8 to 25 percent less digestible dry matter from high-concentrate rations fed for high levels of production.

Ewing and Smith (1917) concluded, after their studies with steers, that ration passage through the digestive tract is a function of particle size and intake. The smaller particle size of high grain diets would therefore be a factor in rate of passage. King and Moore (1957) found rate of passage through the digestive

tracts of Hereford steers to be greatly influenced by particle size of the ration. In their study, inert plastic particles of 24.9 to 226 mg./particle in weight were fed in the ration. The smaller sized particles (28 mg./particle) were found to have the greatest rate of passage.

Blaxter and McC. Graham (1956), in their studies with sheep, found that dry matter digestibility was affected by particle size and intake level. Grass hay was fed to the sheep in a coarsely chopped or finely ground form at the rate of 600 g./hd./day. Dry matter digestibility decreased from 80.6 percent for coarsely chopped hay to 73.1 percent for finely ground hay. Intake of the rations was increased to 1500 g./day, and dry matter digestibility of the coarsely chopped hay diet decreased to 75.6 percent. The dry matter digestibility of the finely ground hay diet at the 1500 g./day intake level decreased to 64.3 percent. The workers concluded the physical factors associated with the hay (particle size) changed the rate of passage and reduced dry matter digestibility. Blaxter et al. (1956) fed long, medium ground, and cubed or finely ground and cubed grass hay to six wethers at intakes of 600, 1200, and 1500 g./hd./day. The apparent ration digestibility of the long hay diet decreased from 80.3 to 79.4 percent, and mean time spent in the digestive tract (hours) also decreased from 103 to 68 hours as intake increased to 1500 g./hd./day. The apparent

digestibility of the medium ground hay diet decreased from 76.9 to 69.9 percent, with mean time in the digestive tract decreasing from 74 to 42 hours as intake increased to 1500 g/hd./day. The intake of the finely-ground hay diet was increased to 1500 g./hd./day and ration digestibility decreased from 75.9 to 65.4 percent, with mean time in the digestive tract reduced from 53 to 34 hours. Rodrique and Allen (1959) fed coarsely-ground, medium-ground, finely-ground or long hay to lactating dairy cows. The hay was included in the ration at 2 parts corn to 1 part hay. Dry matter digestibility was decreased for all forms of the processed hay when compared to the long hay in the diet. The average time spent in the digestive tract was measured as the time in hours 5 percent of the total dye stained particles fed with each form of hay spent in the digestive tract. The average hours spent in the digestive tract for the long hay, coarsely ground hay, medium ground hay, and finely ground hay was 21.5, 16, 16, and 13 respectively. The percentage of milk fat was also depressed for the processed hay diets in comparison to the long hay ration.

Impaired Activity of Pancreatic Alpha Amylase

Wheeler and Noller (1977) noted in their studies with cattle and sheep that a low pH in the small intestine and feces was accompanied by significant amounts of starch in the feces. The workers increased

the ration calcium level with limestone from .3 to .9 percent of the ration dry matter in high-moisture corn diets fed to steers. Small intestinal pH in these steers increased from 5.61 for the .3 percent calcium ration to 6.68 for the .9 percent calcium ration. The workers noted that when pH of the small intestine was increased one pH unit, the amount of starch appearing in the feces (percent of fecal dry matter) decreased from 32.44 to 9.18 percent. These workers concluded that the limestone caused the pH of the small intestine to be closer to the pH of optimum activity for pancreatic alpha amylase, resulting in more efficient utilization of starch.

The pH of optimum activity for porcine pancreatic alpha amylase is 6.9 (White et al., 1968). Zinn and Owens, personal communication, provided evidence that the pH of optimum activity is also 6.9 for bovine pancreatic alpha amylase. The pH of the intestinal contents was increased from 6.0 to 6.5 and the rate of starch digestion increased 57 percent. When the pH was increased to 7.0 or above, the rate of starch disappearance was depressed.

The concept that enzymes possess a pH of optimum activity is not new nor unproven (Tauber, 1949). Proteolytic enzymes present in pancreatic secretions such as trypsin, chymotrypsin, and carboxypedtidase have pH optimums of 8.0; 8.0; and 7.6 respectively (Ben Ghedalia et al., 1974). A broad range exists in the optimum pH for enzyme activity among enzymes. The enzyme pepsin will have a

pH optimum of 1.5, while arginase will have a pH optimum of 9.5 to 9.9 (White et al., 1968).

Enzymes, such as pancreatic alpha amylase, are ampholytes (both negatively and positively charged) and possess many ionic groupings contributed from the amino acid residues comprising the primary structure of the enzyme. The catalytic effects of an enzyme are the product of the ionic groupings present at the active site of the enzyme. The ionic groupings (amino or carboxyl groups present on the side chain of certain amino acids) need to exist in either an ionized or unionized state for catalytic activity to occur (White, 1968).

No description in the literature could be found concerning the specific ionic groups present at the active site of pancreatic alpha amylase, or the effect pH would have on the catalytic activity of the ionic groupings. However, similarities exist between pancreatic alpha amylase and the enzyme lysozyme that enable lysozyme to be used as a model in describing the effect of pH on active site ionic groupings in alpha amylase. The enzyme lysozyme is similar to alpha amylase in that both are hydrolytic endo enzymes capable of catalyzing the hydrolysis of acetal linkages between sugar residues. The substrate for lysozyme is a polysaccharide consisting of alternating glycosidic residues of N-acetyl glucosamine and N-acetyl muramic acid joined by beta 1-4 glycosidic linkages. Lysozyme is also capable of catalyzing the hydrolysis of the

beta 1-4 linkages between repeating units of N-acetyl glucosamine (Bender and Brubacher, 1973). Lysozyme and alpha amylase both possess a binding groove in which the substrate is held by extensive hydrogen bonding and nonpolar interactions. The binding site for alpha amylase will bind at least 5 glucose units from amylose or amylopectin (Robyt and French, 1969).

The pH of optimum activity for lysozyme is 6.0 because of the side chain carboxyl group of a glutamic acid residue present at the active site. The glutamic acid residue is present at the bottom of the binding groove in a strongly nonpolar environment, giving the side chain carboxyl group a pKa of 6.3 rather than the normal pKa of 4.0 to 4.5. Therefore, at the normal operating pH 6 of lysozyme, the carboxyl group will have a greater tendency to exist in the acidic form and will be capable of donating a proton to the bridge oxygen between sugar residues of the substrate (Bender and Brubacher, 1973). Situated in close proximity of the cleaved bond is an aspartic acid residue. This aspartic acid residue is in a highly polar area of the binding pocket which will allow its side chain carboxyl group to have a pKa of 4.0 and a negative charge at pH 6. The close proximity of the aspartic acid residue, with its negative charge, to the site of bond cleavage allows the negative charge to neutralize the developing positive charge on the anomeric carbon of the cleaved sugar residue. The structure of this sugar residue is

stabilized long enough for water hydrolysis to take place (Bender and Brubacher, 1973). Pancreatic alpha amylase is comprised of 25 percent aspartic and glutamic acid residues. Alpha amylase will make use of the imidazole group (pKa 6.0) from a histidine residue to protonate the bridge oxygen instead of the carboxyl group of a glutamic acid residue (Bohinski, 1979).

Vallee et al. demonstrated that the activity of porcine pancreatic alpha amylase is also dependent on the presence of inorganic ions such as calcium. Porcine pancreatic amylase was found to contain a minimum of one gram atom of calcium per mole of enzyme protein. Zinc was the only other metal present in significant amounts. The amylase was incubated with the metal chelating agent ethylenediamine tetra acetate (EDTA). The activity of the amylase was decreased immediately but was restored with the addition of .02 mole of calcium ions.

In order for a suboptimum pH to adversely affect the utilization of starch in the small intestine, the quantity of enzyme must also be limiting. This concept is defined by Michaelis-Menten principles of first and zero order kinetics. The initial rate of a reaction is dependent on the concentration of the substrate (first order enzyme kinetics). The plentiful quantity of substrate will allow the rate of enzyme-substrate complex formation to increase until a saturation point is reached and there is no longer sufficient enzyme present. The addition of more enzyme will allow the rate of the reaction to

increase further (zero order enzyme kinetics). Therefore, impaired activity of alpha amylase could be overcome by greater quantities of the enzyme (Bohinski, 1979).

Orskov and Fraser (1968) suggested there is a limit to the amount of amylase present in the intestine of sheep. The workers found when the amount of starch reaching the abomasum equalled 5 percent of the dietary intake, starch at the terminal ileum increased at an increasing rate. Karr et al. (1966), in work with 360 kg. Angus steers found that as the amount of starch in the abomasum exceeded 778 g., the quantity of starch appearing at the posterior ileum increased dramatically. Larsen et al. (1956), using 8 and 9 month old calves, measured blood glucose levels in response to diets containing commercial or ground yellow corn. Blood samples were taken from the juglar vein at 0, 1, 2, 4, 6, 8, and 10 hours after feeding. There was no appreciable rise in blood glucose levels at any of the sample times after the morning feeding. These workers speculated that the hydrolysis of starch in the small intestine of the ruminant is slow because of limited amounts of intestinal and pancreatic amylases. Siddons (1963) found the activity of alpha amylase in the small intestine of the ruminant to be quite irregular.

There is evidence that the quantity or activity of pancreatic alpha amylase is not limiting. Clary et al. (1967) fed wethers five rations of increasing starch content. The rations were: all alfalfa

hay; 20 percent corn; 40 percent corn, 60 percent corn, or 80 percent corn, with the remainder of the ration as alfalfa hay. The workers found that as the amount of corn increased in the ration amylase activity in the small intestine also increased. The volume of bile and pancreatic juice also increased from 558 to 1480 milliliters. Taylor (1958) found in sheep studies that feeding would boost amylase activity in the small intestine. The increased activity, however, would be sustained for only 1 to 2 hours after feeding. Delay (1972) fed Herford X Angus steers (average weight 330 kg.) diets of either 95 percent or 70 percent concentrate (flaked corn) and measured amylase activity in the duodenum. Amylase activity was defined as one unit of amylase activity when one micro-mole of maltose was released. No difference between treatments in amylase activity was noted, but Delay concluded the amount of amylase was not limiting due to the uniformity of starch disappearance in the lower tract regardless of the amount of starch presented for digestion.

Exogenous Buffers in Ruminant Rations

Exogenous buffers have been used for many years in ruminant rations in an effort to correct the acidity problem present in the gastrointestinal tract when high-grain, low-roughage rations are fed (Wheeler, 1980a). The focus of attention has been the control of reticulorumen pH with chemical buffers such as sodium or potassium

bicarbonate (Nicholson and Cunningham, 1961; Emery et al., 1964; Huber et al., 1969). There are several excellent reviews concerning the use of buffers in ruminant rations (Wienberg and Sheffner, 1976; Muller and Kilmer, 1979; Trenkle, 1979).

The principal buffering site for limestone (a mineral buffer) is in the small intestine. Wheeler and Noller (1977) used limestone to increase the ration calcium level in their studies with steers fed all-concentrate rations and found that intestinal pH also increased. Chemical buffers such as sodium hydroxide, sodium, or potassium bicarbonate are more effective in buffering acidity in the reticulorumen than in the small intestine. Wheeler (1980a) indicated limestone is used as a lower tract buffer because of the slow absorption rate of calcium from the forepart of the ruminant digestive tract. Sodium or potassium, in contrast, is readily absorbed from the reticulorumen.

Nicholson et al. (1963), using rumen-fistulated steers, fed all-concentrate rations, compared sodium bicarbonate to limestone in buffering the reticulorumen. The workers added 5.7 percent sodium bicarbonate or 5.7 percent limestone to the steer rations. The sodium bicarbonate caused reticulorumen pH to increase from 5.8 to 6.5. The limestone treatment had no effect on reticulorumen pH. Emery et al. (1964) also found limestone had no effect on reticulorumen pH when included in a diet fed ad libitum to dairy

cows in mid lactation. In this study, the limestone did increase the blood glucose levels of the cows when compared to a sodium bicarbonate treated group. The increased blood glucose levels may point to an increased uptake of glucose in the small intestine because of more efficient utilization of starch. The workers did not suggest that this increase in blood glucose levels was due to increased efficiency of starch utilization.

The Relationship Between Fecal pH and Fecal Starch

In the previously cited work by Wheeler and Noller (1977), the workers found that fecal pH was highly correlated with the amount of starch appearing in the feces. In two trials conducted with either Holstein steers or crossbred steers and heifer calves, the correlation coefficients relating fecal pH to starch in the feces were -.82 and -.92, ($P < .01$) respectively. Wheeler *et al.* (1976) studied the relationship of fecal pH to fecal starch when lactating dairy cows were fed *ad libitum* rations of either 75:25; 60:40, or 45:55 ratios of forage to concentrates. Fecal pH, the percent of starch per fecal dry matter, and the correlation coefficients for each of the three diets were as follows: 75:25, 6.46, 4.62, -.88; 60:40, 6.09, 7.45, -.85; 45:55, 5.95, 10.66, -.93. The lower fecal pH was associated with higher levels of starch in the feces.

Limestone in Ruminant Rations

Limestone (calcium carbonate) is routinely used in ruminant rations as a source of calcium. The use of limestone to raise ration calcium levels above those recommended by the National Research Council (NRC, 1976) in an effort to reduce small intestinal acidity and improve starch utilization has been receiving increased attention.

Wheeler and Noller (1976a), using lactating Holstein cows, studied the effect of increasing ration calcium levels with limestone on performance, fecal pH, and the amount of starch in fecal dry matter. In one trial, 54 lactating Holstein cows were fed ad libitum a ground shelled corn and corn silage diet. The treatments were .5, 1.0, and 1.5 percent calcium in the ration dry matter. The cows fed 1.0 and 1.5 percent calcium in the diet consumed less feed and produced the same amount of fat-corrected milk, indicating more efficient use of the ration. The fecal pH values were 5.99, 6.25, and 6.62 for the .5, 1.0, and 1.5 percent calcium levels respectively. The fecal pH values were all significantly different ($P < .05$). Trial two was conducted with 36 lactating Holstein cows fed high concentrate rations ad libitum with .5 or 1.5 percent calcium in the ration dry matter. Dry feed intake and milk production per day were the same for both levels of calcium in the diet. However, the cows receiving the lower level of calcium lost an average of -.27

kg./day, while the cows receiving the higher level of calcium gained an average of .66 kg./day. The higher calcium treatment caused the percent fecal starch to decrease from 7.96 percent to 3.0 percent, and fecal pH to increase from 6.13 to 6.57. Wheeler (1980b) using limestone, fed ration calcium levels of .5 or 1.5 percent of the ration dry matter to 40 lactating Holstein cows. The rations were fed ad libitum and consisted of a 50:50 ratio of corn silage to rolled shelled corn. The cows receiving the higher level of calcium produced 7.3 percent more milk. Starch digestibility was also increased with the higher level of calcium from 85.9 percent to 94.6 percent. Dry matter and cell wall digestibility were increased 3.4 and 3.8 percent respectively with the higher calcium ration.

Wheeler and Oltjen (1979), in a 140 day trial with finishing steers, demonstrated that cement kiln dust (27.3 percent calcium) also will increase intestinal and fecal pH. They fed 32 steers (average weight 308 kg.) ad libitum diets of 53.2 percent timothy hay and 46.8 percent concentrate containing cement kiln dust providing either .37 percent or 1.3 percent calcium in the ration dry matter. Steers fed the higher calcium diet had a higher intestinal pH (6.87 versus 6.37) and a higher average fecal pH (6.91 versus 6.45) than the lower calcium rations. The steers receiving the higher-calcium diet also gained 36.9 percent faster, and were 32.4 percent more efficient at converting feed to gain.

Noller et al, (1980) found that the major form of calcium in cement kiln dust was calcium carbonate. The workers also noted that 48.4 to 86.8 percent of the total neutralizing capacity of cement kiln dust can be attributed to the carbonate component. Zinn et al. (1979) conducted a metabolism trial with four steers (average weight 295 kg.) in order to investigate the influence of cement kiln dust on nutrient utilization of a high concentrate ration. The kiln dust was added to provide .63 or 1.49 percent calcium in the ration. The steers fed the higher calcium ration digested dry matter and starch 3.2 and 5.1 percent more efficiently than the lower calcium treatment.

Increasing the calcium level in ruminant rations with limestone does not always result in increased performance. Colovos et al. (1955) increased the calcium level in diets fed to 18- to 24-month old heifers by adding 2 percent limestone. The addition of limestone decreased the digestibility of the ration protein and energy. Zinn and Owens (1980b) added 2.5 percent calcium carbonate to a high concentrate diet (72.2 percent corn and 20.0 percent prairie hay) fed to Angus steers (average weight 308 kg.) that were fitted with dual re-entrant cannulas. The workers found that distal ileal and fecal pH were not significantly increased with the added calcium. Starch digestion did not increase in the small intestine but increased 30 percent in the rumen. Thornton et al. (1978) fed high

moisture corn diets ad libitum to 10 Angus steers (average weight 395 kg.) and increased the ration calcium level with dolomitic limestone from .36 to .44 percent calcium in the ration dry matter. The higher calcium level increased fecal pH from 6.2 to 6.9, but did not significantly improve starch digestibility. Noller (1980) would attribute the lack of results from this trial to the use of dolomitic limestone which contains significant amounts of magnesium and has a slower rate of reactivity than a calcitic limestone.

The Influence of Limestone Characteristics

Noller (1980) indicated that the variable responses obtained using mineral buffers such as limestone may be due to differences in their chemical and physical properties. Factors which will influence the efficacy of a mineral buffer include the following: 1) source, 2) particle size, 3) chemical properties and 4) physical properties.

Wheeler (1981) indicated the reactivity rate of limestone was a critical factor influencing its effectiveness as a buffer. Noller (1980) stressed that given the increased rate of passage through the digestive tract of high grain diets, the time required for a buffer to react with acid would be a critical factor. Wheeler (1981) developed a method to evaluate the reactivity rate of a buffer such as limestone. The time required for a buffer to neutralize 50 percent of a given acid solution was measured in

seconds and was termed T_{50} or reactivity rate. The reactivity of limestone is dependent on the type of limestone used and on the particle size of the limestone. Limestones are either calcitic ($CaCO_3$) consisting of alternating layers of calcium (Ca^{++}) and carbonate ($CO_3^{=}$) ions or dolomitic ($CaMg(CO_3)_2$) with alternating planes of calcium, carbonate, and magnesium (Mg^{++}) ions. Dolomitic limestone will have a slower rate of reactivity than calcitic limestones. Finer particle limestone will have a greater rate of reactivity than will a coarser particle limestone. The rate of reactivity of limestone has been improved when ground to a finer particle size (Wheeler, 1981).

Wheeler (1979) evaluated the effectiveness of three different limestones from the same source, but with different particle sizes and rates of reactivity. Particle size was defined as the percent of particles passing a 280 mesh screen. The particle size and reactivity (measured in seconds) of the three limestones were as follows: (1) 4, 4110; (2) 32, 1230; (3) 86, 60. This demonstrates that as particle size decreases reactivity rate also decreases. Three different calcium levels of .35, .70, and 1.05 percent calcium in the ration dry matter were used as treatments. In the trial, 324 head of finishing beef steers (average weight 264 kg.) were fed a basal ration consisting of 25 percent corn silage and 75 percent concentrate. Average daily gain (kg./day) for the three different

limestones at each of the three ration calcium levels were as follows: (1) .84, .98, 1.06; (2) 1.0, 1.1, 1.3; (3) 1.3, 1.3, 1.4. The values for fecal pH and fecal starch for each of the limestones were as follows: (1) 5.83, 27.4; 6.08, 23.3; and 6.21, 18.6; (2) 6.26, 19.3; 6.47, 15.9 and 6.61, 13.3; (3) 6.56, 14.8; 6.74, 10.5 and 6.89, 5.1. Average daily gain improved with increasing calcium level in the ration, and with decreasing particle size and reactivity rate. Wheeler et al. (1980a) again evaluated three different limestones with different particle sizes and reactivity rates as sources of calcium in finishing rations for 294 kg. steers. Three treatments used consisted of either .35, .65, or .95 percent calcium in the ration dry matter. The rations were corn grain and corn silage based. The values for particle size and reactivity rate for each of the three limestones were as follows: (1) 4, 4110; (2) 86, 60; and (3) 100, 5. Average daily gains again increased with increasing calcium level. The steers fed limestone 3 had the highest average daily gain, fecal pH, and lowest percent fecal starch. The finer limestone also increased the pH of the reticulorumen environment. Wheeler et al. (1980b) conducted a 168 day feeding trial, using 263 kg. Simmental crossbred steers, to evaluate the influence of ration calcium level and/or rate of limestone reactivity on feedlot performance and gastrointestinal pH. The steers were fed a 25 percent corn silage-75 percent concentrate diet ad libitum. The

particle size (percentage passing through a 53 μm sieve) and reactivity rate for each of the limestones evaluated were as follows; (1) 4, 4110; (2) 32, 1230; (3) 86, 60. Diets within each type of limestone were formulated to contain .35, .70, or 1.05 percent calcium in the ration dry matter. Average daily gains (kg.) for each type of limestone at each of the three ration calcium levels were as follows: (1) .77, .92, 1.10; (2) .85, 1.08, 1.29; (3) 1.10, 1.31, 1.24. Average daily gain was found to increase with ration calcium level and limestone reactivity rate. The pH level in the reticulorumen of steers fed limestone 1 did not increase significantly with increased ration calcium level. However, the pH of the reticulorumen of steers fed limestones 2 and 3 did increase significantly from 5.97 to 6.64 and from 6.32 to 6.84 respectively as ration calcium level increased. The workers concluded the limestones of medium to fast reactivity rates are effective in buffering the reticulorumen. The pH of the small intestine, and feces were found to increase significantly as ration calcium level increased using all three types of limestone.

Wheeler et al.(1980b) investigated the effectiveness of three different geological types of limestones in finishing cattle rations. The type of limestone evaluated and their respective particle sizes and reactivity rates were as follows: (1) dolomitic, 83, 4830; (2) hard calcitic, 82, 2150; (3) soft calcitic, 78, 40. The workers

conducted a 112 day feeding trial using 108 beef steers fed a ration consisting of a 25:75 ration of corn silage to concentrate. The ration calcium level was .80 percent calcium on a dry matter basis. Average daily gains, fecal pH, and percent fecal starch (expressed as a percent of the fecal dry matter) for each of the three types of limestone were as follows: (1) .81, 6.09, 27.1; (2) 1.14, 6.38, 15.2; (3) 1.31, 6.84, 8.6. The soft calcitic limestone produced the highest daily gains, highest fecal pH, and lowest percent fecal starch. The workers concluded the efficacy of limestone is dependent on geological type, which in turn effects the rate of reactivity.

Perry et al. (1980) investigated the effects of two types of limestone (feed grade versus finely ground) and two levels of calcium (.46 and 1.06 percent of the ration dry matter) in the diet of 234 kg. finishing heifers. Each limestone was fed at the low and high ration calcium level in simultaneous trials. The heifers fed the 1.06 percent calcium level of the finely ground limestone gained 1.22 kg. per day, while those heifers fed the lower level of calcium gained 1.16 kg./day. Daily gain between heifers fed the feed grade limestone at the 1.06 percent ration calcium level and those receiving the finely ground limestone at the .46 percent ration calcium level did not differ. There was no difference among treatments in fecal pH, but the heifers on the feed grade limestone at the .46 percent calcium level had a slightly lower average fecal

pH (6.3 versus 6.6) than the other three treatments. Prokop (1980) compared feedgrade limestone to a powdered limestone which would pass a 200 mesh screen in a feeding trial with 48,286 kg. steers fed a 90 percent concentrate ration ad libitum. The cattle were allotted to three treatments which consisted of: (1) feed grade limestone, .47 percent calcium per ration dry matter; (2) powdered limestone, .47 percent calcium per ration dry matter; (3) powdered limestone, 1.14 percent calcium per ration dry matter. Daily gain, or feed per gain between the feed grade or powdered limestone groups did not differ. However, the powdered limestone fed at the .47 percent calcium level tended to increase average daily gain .07 kg. and reduce by .09 kg. the feed required per kg. of gain.

Calcium Levels in Beef Cattle Rations

The increased performance often observed in cattle fed elevated calcium levels from limestone may be due in part to meeting the calcium requirements of the animal. Cereal grains such as barley, corn, milo, oats, and wheat contain negligible amounts of calcium (.02 to .10 percent). Therefore, high grain finishing rations will be deficient in calcium unless supplemented with a mineral source such as limestone (Beeson et al., 1974).

The calcium requirements for beef cattle will vary with age, growth rate, sex, and lactation. The recommended ration level of

calcium for a 350 kg. to 500 kg. finishing steer gaining 1.3 to 1.4 kg./hd./day is .22 to .34 percent calcium in the ration dry matter or 22 to 28 g. per day. The recommended ration calcium levels for 350 kg. to 450 kg. finishing heifers gaining 1.0 to 1.1 kg./hd./day is .22 to .26 percent of the ration dry matter or 19 to 21 g. per day (NRC, 1976). Blizzard (1939), in early work at the Oklahoma Experiment Station, found that when .08 kg. of finely ground limestone was added to a finishing ration for steers, average daily gain increased from .96 to 1.03 kg./hd./day. Varner and Woods (1972a) conducted a 137-day feeding trial with steers fed a 85 percent concentrate ration ad libitum with limestone to vary calcium levels. Rations 1, 2, 3, and 4 were formulated to contain .20, .31, .42, and .53 percent calcium respectively on a dry matter basis. Average daily gain (kg. per day) and feed per gain (kg. feed/100 kg. gain) were as follows: (1) .97, 907; (2) 1.10, 833; (3) 1.18, 785 and (4) 1.06, 840. Average daily gain increased and feed efficiency improved with increasing calcium in the ration up to .42 percent calcium. Average daily gain and feed efficiency of the .53 percent calcium level was improved over the .2 percent level but was still less than the .31 and .42 calcium level. The steers assigned to the .42 percent calcium level were consuming 34.4 g. of calcium per day, more than 22 to 28 g./day recommended by the National Research Council. Varner and Woods (1972b) conducted a metabolism study with

Hereford steers fed increasing calcium levels in rations consisting of 70 percent concentrate. The ration calcium levels varied from .41 to .70 calcium on a dry matter basis. The digestibility of ration energy increased significantly from 66.2 to 70.9 percent when the calcium level was increased to .7 percent calcium. Protein digestibility also increased from 68.8 percent to 74.2 percent when the higher calcium level was fed.

Bushman et al. (1967) found no difference in gain among treatments when steers were fed diets consisting of .15, .3, or .6 percent calcium in the ration dry matter. Steers used were fed a basal ration of 84.4 percent finely ground corn and 14.6 percent soybean meal with no roughage. The steers receiving the .6 percent level of calcium in their diet had a 19 percent thinner backfat cover than the lower calcium rations.

Beef cattle are better able to tolerate wider calcium to phosphorus ratios than are nonruminants (Beeson et al., 1975). Dowe et al. (1957) found average daily gain decreased in Hereford calves fed rations containing calcium to phosphorus ratios greater than 4.34 : 1. Wise et al. (1963) fed calcium to phosphorus ratios ranging from .4 : 1 to 14.3 : 1 to 114 kg. Hereford calves. The ratios from 1:1 to 7:1 gave similar and satisfactory performance results. The authors did not specify the gain per day or feed per gain. Calcium to phosphorus ratios less than 1:1 resulted in a

marked decrease in performance. The serum calcium levels were not affected by the dietary intake of calcium. However, when dietary phosphorus was increased, a linear decrease in serum calcium level occurred.

Wheeler et al. (1981a) found that ration calcium level had no effect on blood serum levels of calcium or phosphorus in feedlot cattle. In this study the workers fed .35, .70, or 1.05 percent calcium in the ration dry matter for a period of 168 days to 263 kg. Simmental crossbred steers. At the time of slaughter the right radius-ulna was removed, and the specific gravity determined. The specific gravity of the radius-ulna was found to increase as the ration calcium level increased. They noted that as calcium intake exceeded 67 mg./ kg. of bodyweight calcium absorption and retention increased. The increased calcium retention was thought to be associated with greater amounts being retained on the skeletal framework. Braithwaite and Riazuddin (1971) in studies with sheep, found that nearly all dietary calcium absorbed above the level required for maintenance was retained. This retention was the result of increased accretion of calcium into bone. These workers also found that calcium absorption was directly related to calcium intake for young wethers. However, calcium intake had no effect on absorption in mature 16 month old wethers.

Chapter 3

EXPERIMENTAL PROCEDURE

General

Four feeding trials evaluating various levels of calcium in the diet of feedlot cattle were conducted at the Montana Agricultural Experiment Station Feedlot, Bozeman, Montana. Cattle used were produced at the Red Bluff Research Ranch, Montana Agricultural Experiment Station, Norris, Montana, or the University Agricultural Experiment Station Farm located 1.6 km. west of the Montana State University campus, or at the Livestock and Range Research Station, Miles City, Montana. The cattle were ear tagged for identification after their arrival at the feedlot and vaccinated for IBR-PI3 (red nose and shipping fever), Bovine Virus Diarrhea (intramuscular), Hemophilus Somnus (Somnigen), and with a Seven Way Clostridial vaccine. Ruelene was poured on for grub control, and the steers were implanted with 36 mg. of Ralgro (Zeranol) in the left ear. Straw was used as bedding and added to the pens when needed to keep the cattle as dry as possible.

Initial and final weights of the cattle were taken after an overnight shrink (12 hours) when the cattle were restricted from feed and water at 8:00 p.m. the preceding evening. On the evening prior to taking the final shrink weight, feed remaining in the bunk was weighed and subtracted from the recorded amount fed. Individual

check weights without a shrink were taken every 28 days. The cattle were inspected for the incidence of founder during each trial.

Rations and Feeding

Trace mineralized salt was offered free choice to the cattle in either a loose or 22.7 kg. block form. The remaining salt was weighed every 28 days to determine average daily consumption. The grain mixture consisted of 80 percent ground barley and 20 percent beet plup in trial I, and 75 percent ground barley, 20 percent ground wheat and 5 percent beet pulp in trials II, III, and IV. Supplements were formulated to contain 20 percent crude protein on a dry matter basis and were top dressed on the ration at the rate of .91 kg. per head per day. The supplements were formulated to give 12 percent crude protein on a dry matter basis in the total finishing rations in trials I, II, and IV. Basal rations consisted of the grain mixture, medium quality chopped native grass hay, and supplement. Rations were divided equally between the morning and afternoon feeding. Grain mixtures were weighed into large cans before being spread into fenceline bunks. Supplements were weighed into small rubber pails numbered according to the pen in which they were fed. The chopped native grass hay was weighed into metal tubs before being spread into the bunks. During the last 28-day period of trial IV, the grain mixture and chopped hay were weighed into a Butler mixer wagon, Model 1830, and fed once daily at the morning

feeding from the wagon. Supplements were top dressed over the ration.

Water was provided in each pen by an electrically heated automatic waterer, which was cleaned periodically during the trial.

Proximate analysis of the ration ingredients were obtained according to A.O.A.C. (1979) procedures. Calcium percentages were determined by a modified Kramer and Tisdall method (Clark-Collip, 1925) and phosphorus percentages by the method of Fiske and Subbarow (1925).

Characterization of Limestone

The source and geological type of limestone did not differ throughout the four feeding trials. The limestone was purchased from the Peavey Company of Belgrade, Montana, who in turn obtain their limestone from one quarry.[1] The limestone used as the source of calcium in the feeding trials was classified as a hard calcitic and characterized geologically as being from the Madison Formation and the Mississipian Period.

Physical degree of fineness of the limestone was determined by passing a 100 g. dry sample through 710, 500, 250, 106, and 90 micrometer U.S. Standardized Seives. The rate at which the limestone would react with acid or the rate of limestone would consume protons

---

[1]Big Horn Calcium Company, Warren, Montana.

was evaluated at the Woodson-Tenent Laboratories, Inc.[2] by using a pH-Stat titration procedure (Noller et al., 1980). This procedure is described by Steinberg et al., (1965) as the time in seconds (T_{50}) to add one-half the total amount of .3N hydrochloric acid needed to neutralize a solution of a specific pH into which a 0.5 g. sample of limestone has been added. Reactivity rate was determined at pH 3 and 6, since the first is indicative of pH conditions in the abomasum and fore-part of the small intestine, and pH 6 was representative of the pH in the rumen of cattle consuming high grain-low roughage diets (Noller et al., 1980).

Fecal pH

Fecal grab samples were obtained for pH analysis from all the cattle in finishing trials I, II, and IV. Samples were taken once during the trial in trial I and at three times during trials II and IV. The samples were obtained using plastic artificial insemination gloves. After obtaining the sample, the glove was inverted and tied, holding the sample until pH was determined. The pH was determined shortly after sampling, or the sample was frozen until the pH could be determined at a later time.

---

[2]Woodson-Tenent Laboratories, Inc., 345 Adams, P.O. Box 2135, Memphis, Tennessee, 38101.

One part fecal sample (9 ml.) was mixed with approximately one part distilled water (11 ml.) in a 100 ml. beaker. The pH of the sample was then determined as it was stirred with a magnetic stirer using a Beckman pH meter equipped with an all purpose combination electrode.

Fecal Alkalinity

The effect of treatment on fecal alkalinity was determined only in Trial I. This determination was made by use of the potentiometric method for low alkalinity (APHA, 1971). The pH of the sample was first determined according to the methods previously described. After the initial pH was read, a 50 ml. buret containing .01 Normal sulfuric acid was placed over the beaker containing the sample and distilled water. The acid was titrated into the beaker in 1 ml. increments while being stirred with the magnetic stirrer and allowing the pH to equilibrate. The milliliters of sulfuric acid needed for the sample to reach pH 4.5 and 4.2 were recorded and used to determine a fecal alkalinity value derived by the following equation:

$$\text{mg. } CaCO_3 \text{ per liter of sample} = \frac{(2C-D) \times N \times 50{,}000}{\text{ml. of sample}}$$

C = milliliters of acid titrated for sample to reach pH 4.5.

D = total milliliters of acid titrated for sample to reach pH 4.2

N = normality of the acid (0.01)

Fecal Starch

A subsample, (sufficient quantity to yield at least .8g. of air dry sample) was placed on an aluminum foil pan before a small fan for a period of three to four days and air dried. Subsamples were turned and broken periodically to prevent the growth of mold and aid drying. Air dried samples were ground in a Waring coffee mill and placed in a plastic Whirl pack, with each Whirl pack numbered according to the ear tag number of the steer from which the sample was obtained.

Fecal starch content was determined on an air dry basis using the enzymatic digestion of Smith (1969) with alpha-1,4-glucan glucohydrolase. Determination of reducing sugars was conducted using the phenol-sulfuric colorimetric procedure of Hodge and Hofreiter (1962). Absorbance was determined with a Bausch and Lomb Spectronic 20, spectrophometer at 490 nm wavelength. Twenty-one culture tubes (20 mm. o.d. and 150 mm. length) were standardized according to absorbance. The tubes were chosen according to similar absorbance when filled with 10 ml. of distilled water and placed in the spectrophotometer.

A one gram sample was oven dried at 100 C for 24 hours. The

---

[3]Sigma Chemical Company, P.O. Box 14508, St. Louis, MO. 63178.

resulting dry matter values were then used to convert the percentage of starch in each fecal sample to a dry matter basis.

Carcass Data

Carcass data were collected at the termination of finishing trials I, II, and IV after the cattle were shipped a distance of 193 km. to Midland Packing Company of Billings, Montana, for slaughter. The cattle were sold on the basis of carcass grade and weight with slaughter occurring within 12 hours after arrival at the plant. Steer identity was maintained by transferring the ear tag to the carcass at the time of slaughter. Hot carcass weights were determined at this time, and the number of abscessed livers were recorded.

Carcass data were collected 48 hours after slaughter in trial I, and 24 hours after slaughter in trials II, and IV. Quality grades were assigned to the carcass in one-third increments and a marbling score of the rib eye sectioned between the 12th and 13th ribs by a U.S.D.A. grader. Numerical values were assigned to the slaughter grade and marble score to aid in statistical analysis (A.M.S.A., 1977). Backfat thickness was measured at the 12th rib to the nearest .1 inch and converted to centimeters. The rib eye was traced at the 12th rib by using a number 2 lead pencil and .003 matte acetate paper frosted on one side. The rib eye area was then determined

from the tracing by using the average of three planimeter measurements.

Trial I

Sixty-four head of 323 kg. Simmental cross steer calves (produced at the Livestock and Range Research Station) were used in a high-grain, low-roughage finishing trial lasting 119 days. The cattle had been used in a previous experiment in which a high-roughage, low-grain growing ration had been fed.

The cattle were separated by initial shrink weights into light (352 kg.) and heavy (376 kg.) groups allowing a light (L) and heavy (H) replication of four treatments. The cattle were then stratified by weight and sire, and randomly alloted within each weight grouping to one of four pens or a total of eight pens used in the trial with eight steers per pen. The four treatments evaluated were assigned to each of the four pens within each replication.

The pens measured 5.3 m by 8.4 m and allowed each steer an area of 5.6m^2. Fence line bunks protected by partial roof cover provided .67 m of bunk space per steer. A board fence 2.4 m in height at the south of the pens provided a partial wind break. Water was provided by automatic waterers. Loose, trace mineralized salt was provided free choice in wooden boxes located at the east end of each bunk.

Table 1. Design of Trial 1

Replication	(L)	(H)	(L)	(H)	(L)	(H)	(L)	(H)
Lot Nos.	9	5	10	16	11	7	12	8
No. Steers	8	8	7[a]	7[b]	8	8	8	8
% Ca. in ration	.3[c]		.3[c]		.6		.6	
% P. in ration	.3		.3		.3		.3	
Ca:P ratio	1:1		1:1		2:1		2:1	
Free choice ml.			X				X	

[a]Steer #120 died 5/28/80. Bloat diagnosed as cause of death.

[b]Steer #104 was diagnosed as a chronic bloater and removed from test 7/24/80.

[c]National Research Council recommendation for the level of calcium in the diet of finishing steers.

Two supplements (Table 2) were formulated to contain 20 percent crude protein, and provide .3 or .6 percent calcium in the ration on a dry matter basis. In addition, a high calcium mineral mix (21 percent Ca and 7 percent P.) was provided free choice to one pen each of cattle receiving the .3 and .6 percent ration calcium levels within light and heavy replications (Table 3).

The composition of the supplements and the high calcium free choice mineral are shown in Tables 2 and 3 respectively.

Samples of the grain mixtures, grass hay, supplements and the free choice mineral were taken every three weeks and analyzed for calcium and phosphorus content. The results of the analyses were averaged and used to determine average daily calcium intake (grams) based on the calculated average daily intake of ration at the end of each trial. The free-choice, high-calcium mineral was weighed every 28 days to determine average daily mineral consumption for the trial.

The cattle were gradually adapted from a high-roughage, low-grain diet to a high-grain, low-roughage finishing diet by increasing the grain mixture .45 kg./hd./day every two days until appetite capacity had been reached. The level of chopped hay in the diet was maintained at approximately 8.0 percent of the total ration on an as fed basis. The hay and grain mixture were fed in combination ad libitum.

Fecal samples were obtained from all cattle and analyzed for pH,

Table 2. Specifications of Supplements for Trial I

MSU Formula No.	780	803
Treatment (% Ca. in ration)	.3	.6
Ingredients	-- Percent of Mixture --	
Barley	56.5	48.0
Wheat Millrun	30.0	30.0
Soybean meal	5.85	7.35
Urea	2.0	2.0
Limestone	3.0	5.0
Dicalcium Phosphate		5.0
Trace Minerals	.1	.1
Vitamin A & D[a]	.05	.05
Molasses	2.5	2.5
	100.0	100.0

[a]Vitamin A added to provide 10,000 I.U. per .91 kg. of supplement.
Vitamin D added to provide 2,000 I.U. per .91 kg. of supplement.

Table 3. Specification of Free Choice Mineral for Trial I

MSU Formula No.	802
Ingredients	-- Percent of Mix --
Dicalcium Phosphate	40.8
Limestone	30.0
Salt	25.0
Wheat Millrun	4.0
Trace Minerals	.2
	100.0

Approxmiate Composition:

Calcium	21 percent
Phosphorus	7 percent

alkalinity, and starch. The samples were obtained at the end of the trail when the final shrink weights were being taken.

At the termination of the experiment, final shrink weights were obtained, and the cattle were shipped to the Midland Packing Company for slaughter and the collection of carcass data.

Trial II

Forty-eight head of 275 kg. crossbred steer calves were used in the finishing trial II, which lasted for a period of 192 days. The cattle were obtained from the Red Bluff Research Ranch, and from the University Experiment Station Farm. The calves were initially divided into two groups according to breed. The heavier group (H) averaged 282 kg. in weight and consisted of Tarentaise cross cattle. The lighter group (L) averaged 269 kg. in weight and consisted of crossbred cattle using Hereford, Angus, and Shorthorn breeds. The calves were stratified by weight and randomly alloted to one of four pens within each replication, or a total of eight pens with six steers per pen.

The steers were housed in pens with the same dimensions as the pens in trial I. Fence line bunks protected by partial roof cover provided .89 m of bunk space per steer. The pens afforded 7.5m^2 of area per steer. Water was provided as in trial I. Trace mineral salt in 22.7 kg. blocks was provided free choice at the end of each bunk.

Table 4. Design of Trial II

Replication	(L)	(H)	(L)	(H)	(L)	(H)	(L)	(H)
Lot Nos.	21	17	22	18	23	19	24	20
No. Steers	6	6	5[a]	4[b]	6	6	6	6
% Ca. in ration	.15		.3[c]		.6		.9	
% P. in ration	.4		.4		.4		.4	
Ca:P ratio	.37:1		.75:1		1.5:1		2.2:1	

[a]Steer #105 removed from trial 4/9/81, diagnosed as chronic bloater.

[b]Steer #219 removed from trial 3/13/81, diagnosed as chronic bloater. Steer #525 died 4/24/81, caused of death diagnosed as bloat.

[c]National Research Council recommendation for the level of calcium in the diet of finishing steers.

Four supplements (Table 5) were formulated to contain 20 percent crude protein, and provide .15, .3, .6, or .9 percent calcium in the ration dry matter per day. The ration phosphorus level was maintained at a constant .4 percent of the ration dry matter.

Prior to the beginning of trial II, it was necessary to reduce the amount of beet pulp in the grain mix to 5 percent, with this level of beet pulp being fed with 75 percent ground barley, and 20 percent ground wheat. This was done because the grain mix used in Trial I (80 percent barley and 20 percent beet pulp) contained too much calcium to allow a .15 percent ration calcium level treatment to be formulated. The new grain mixture was formulated to contain less than .14 percent calcium because of the reduced level of beet pulp. The grain mix, supplements, and chopped native grass hay were analyzed for calcium content at the beginning of the trial, with the analyses results used to determine average daily calcium intake (grams) based upon the calculated average daily ration intake at the end of the trial.

The cattle adapted to a high-grain, low-roughage finishing diet according to the method described in trial I. The chopped native grass hay was limited to 15 percent of the total ration on an as fed basis. The hay and grain mix were then fed in combination ad libitum. Trace mineralized salt in block form was kept before the cattle at all times throughout the trial. The salt was weighed

Table 5. Specification of Supplements for Finishing Trial II.

MSU Formula No.	804	805	806	807
Treatment (% Ca.)	.15	.3	.6	.9
Ingredients	---- Percent of Mix ----			
Barley	69.0	62.1	48.0	33.8
Wheat Millrun	20.0	20.0	20.0	20.0
Soybean Meal	6.2	8.1	11.9	15.6
Urea	2.2	2.2	2.2	2.2
Monosodium Phosphate			.25	.45
Limestone		5.0	15.0	25.3
Trace Minerals	.1	.1	.1	.1
Vitamin A & D[a]	.05	.05	.05	.05
Molasses	2.5	2.5	2.5	2.5
	100.0	100.0	100.0	100.0

[a]Vitamin A added to provide 10,000 I.U. per .91 kg. of supplement.
Vitamin D added to provide 2,000 I.U. per .91 kg. of supplement.

every 28 days to determine average daily salt consumption.

Fecal grab samples were obtained from all cattle at three separate times during the trial for pH analysis. The samples were obtained at the time the 28-day check weight was being taken. Midway through the trial after it was determined the cattle were on full feed, fecal samples were taken for starch analysis.

At the termination of the trial, final shrink weights were taken and the cattle were shipped to Midland Packing Company for slaughter, and the collection of carcass data.

Trial III

Forty head of 235 kg. crossbred steers produced at the Red Bluff Research Ranch and the University Experiment Station Farm were used in a 56-day high-roughage, low-grain growing trial. The cattle were stratified by weight and breed, and randomly alloted to one of four pens with 10 steers per pen. Initial shrink weights were taken at the start of the trial.

The four pens comprising the experimental area measured 10.9 by 7.9 m and provided 8.7 m^2 of area per steer. Fence line bunks provided 1.1 m of bunk space per steer. Water was provided as in trials I and II with automatic waterers. The steers were given access to trace mineral salt free choice in 22.7 kg. block form. The pens were protected on the south by a board fence 2.4 m in height.

Table 6. Design of Trial III

Lot No.	1	2	3	4
No. Steers	10	10	10	10
Treatment (% Ca.)	.24[a]	.60	1.0	1.9
% P. in ration	.22	.22	.22	.22
Ca:P ratio	1.1:1	2.7:1	4.5:1	8.6:1

[a]The National Research Council recommendations = .31 percent Ca. and .28 percent P. in the ration dry matter of a high roughage growing diet for cattle of this size.

The four supplements used in Trial II (Table 5) were used in Trial III allowing four treatments with ration calcium levels of .24, .60, 1.0, 1.9 percent of the ration dry matter.

The objective of Trial III was to determine the effect of ration calcium levels and Ca:P ratios below and above those recommended by the National Research Council on feedlot performance of growing cattle fed high roughage diets. The grain mix daily intake was restricted to 1.0 percent of the steers bodyweight. The chopped grass hay was fed ad libitum. The supplements were fed at the rate of .91 kg. per head per day. Final shrink weights were taken at the termination of the trial.

Trial IV

The forty head of cattle used in Trial III were also used in Trial IV, with the steers remaining in the same pens. Trial IV was a high-grain, low-roughage finishing trial lasting a period of 178 days. The final shrink weights from Trial III were used as the initial weights for Trial IV.

The four supplements used in Trials II and III were also used in Trial IV to give treatment ration calcium levels of .15, .3, .6, and .9 percent in the ration dry matter. The four supplements were fed to the same pens as in Trial III.

The cattle were adapted to a high-grain, low-roughage diet by the same method used in Trials I and II. The chopped native grass hay

Table 7. Design of Trial IV

Lot No.	1	2	3	4
No. Steers	9[a]	9[b]	10	10
Treatment (% Ca.)	.15	.3[c]	.6	.9
% P. in ration	.4	.4	.4	.4
Ca:P. ratio	.37:1	.75:1	1.5:1	2.2:1

[a]Steer #117 removed from trial because of excessive weight loss.

[b]Steer #816 removed from trial because of excessive weight loss.

[c]National Research Council recommendation for the percent calcium in the diet of finishing steers.

was restricted to 15 percent of the total ration on an as fed basis. The grain mix and hay were then fed in combination ad libitum. The cattle had access to trace mineral salt free choice in 22.7 kg. block form. The salt was weighed every 28 days to determine average daily salt consumption. The supplement was fed at the rate or level of .91 kg. per head per day.

The calcium and phosphorus analysis of the grain mix, chopped hay, and supplements, as conducted for Trial II, was used in Trial IV to determine average daily calcium consumption based upon the calculated average daily ration consumption at the end of the trial.

Fecal grab samples were obtained from all cattle as in Trial II, at three different times during the trial. As in Trial II, fecal samples for starch analysis were obtained well after the cattle were considered to be on a full feed of the finishing ration.

The trial was concluded when the final shrink weight was taken. The remaining feed and salt were also weighed at that time. The cattle were then shipped to the Midland Packing for slaughter and the collection of carcass data.

Statistical Analysis

Procedures used for determining regression coefficients, correlations between variables, and detecting differences among more than two treatment means with analysis of variance are found in

Statistical Packages for the Social Sciences (Nie et al., 1975). The Newman-Keuls method was used to separate the means in the event significant differences were detected (Snedecor and Cochran, 1967).

Chapter 4

RESULTS

Chemical Analysis of Feedstuffs

Proximate analysis, calcium and phosphorus content of the grain mixtures chopped native grass hay, free-choice mineral, and supplements fed in the four calcium trials are shown in table 8. Reducing the amount of beet pulp in the grain mix in trial I from 20 percent to 5 percent in trials II, III, and IV also caused a 48 percent reduction in crude fiber content. This may have been a factor in the increased incidence of bloat occurring in trials II, III, and IV.

The particle size distribution and calcium content of the limestone used as a source of calcium in the four feeding trials are shown in table 9, and the reactivity rate and acid consuming capacity shown in table 10. The particle size of the limestone used in these trials was greater than the limestones used by Wheeler (1981a), in which the workers found increased feedlot performance resulting from higher calcium levels in the ration. These workers found that as much as 86 percent of their limestone would pass a 53 μm screen and be retained in the pan. In contrast, only 4.6 percent of our limestone was found to pass through a 90 μm screen and be retained in the pan. However, the reactivity rate of our limestone (T_{50}124, and 69) was comparable (T_{50}60) to the limestone used by Wheeler (1979) in which gain and feed efficiency were improved with 264 kg. steers

Table 8. Proximate Analysis, Calcium and Phosphorus Content of the Feedstuffs Fed in All Four Calcium Trials. As Fed Basis.

Item [a]	DM	CP	CF	EE	NFE	Ash	Ca	P
				---------%---------				
Grain Mix - Trial I	91.0	11.3	6.6	1.6	68.4	3.1	.17	.30
Grain Mix - Trials I, II, III, and IV	90.6	12.4	3.4	1.8	69.7	3.3	.13	.36
Chopped Hay (All Trials)	96.0	8.0	33.7	1.6	44.5	8.2	.33	.13
Supplements and Free-Choice Mineral Fed in Trial I-MSU Formula #								
780-Supplement	91.8	20.0	5.2	2.4	55.9	8.3	1.5	.47
803-Supplement	93.0	17.3	5.2	2.2	55.3	12.7	3.0	1.0
802-Free-Choice Mineral							17.7	7.9
Supplements Fed in Trials II, III, and IV - MSU Formua #								
804	90.1	20.8	4.5	2.5	58.3	4.0	.13	.47
805	90.7	21.4	4.6	2.3	52.9	9.5	2.7	.45
806	92.1	21.9	4.3	2.1	42.2	21.6	5.6	.51
807	93.0	21.0	4.3	1.6	35.1	31.0	12.0	.48

[a] DM = dry matter, CP = crude protein, CF = crude fiber, EE = ether extract, NFE = nitrogen-free extract, Ca = calcium, P = phosphorus

Table 9. Particle Size Distribution and Calcium Content of the Limestone Used in All Four Calcium Trials.[a]

Particle Size of Screen, μm						
710	500	250	106	90	Pan	Calcium %
---------% of Total---------						
29.2	14.7	22.2	21.0	8.3	4.6	41.9

[a]Percent of the total sample that is retained on the screen or in the pan after continuous shaking for 10 minutes.

Table 10. The Rate of Reactivity and Acid Consuming Capacity at pH 3 and 6 of the Limestone[a] Used as the Source of Calcium in All Four Calcium Trials.

pH	Acid Consuming Capacity	T_{50} Stat Seconds[b]
	---mEq H^+ per mole of calcium---	
3	590.0	124
6	66.7	69

[a]This analysis was conducted at the Woodson-Tenent Laboratories, Inc., 345 Adams, P.O. Box 2135, Memphis, Tennessee 38101.

[b]The rate of reactivity expressed in seconds.

fed higher calcium levels in the ration.

Estimation of Daily Ration Intake

In trials I and II it was assumed cattle removed from test consumed approximately the same amount of daily ration as those remaining on test. Therefore, daily ration intake was estimated by dividing the total feed intake of the pen by the number of steers in the pen. However, in trial IV gain of steers removed from test was not found to be comparable to steers remaining on test, and in some instances these steers lost weight during the period. It was decided that by determining the NE_m and NE_g content of the ration, daily feed consumption in trial IV could more accurately be determined by estimating the daily feed required for maintainence and gain for each animal.

Finishing Trial I

The feedlot performance results of the cattle fed in trial I are shown in table 11. There were no significant differences ($P > .05$) found among the four treatments in average daily gain, feed per gain, daily ration intake or the consumption of the high-calcium, free-choice mineral. However, the steers fed the .3 percent calcium without free-choice mineral and the .6 percent calcium with free-choice mineral required an average of .6 kg. less feed per kg. of gain than did the steers fed the other two calcium treatments. Cattle fed the

Table 11. Average Daily Gain, Feed Per Gain and Daily Ration Intake for Cattle Fed in Finishing Trial I.

Lot No.	5 & 9	6 & 10	7 & 11	8 & 12
Treatment (% Ca)	.3	.3 + fcm.[a]	.6	.6 + fcm.
MSU Formula #	780	780 + 802	803	803 + 802
No. Head	16	14	16	16
Average Weights, kg				
Initial	369	355	366	366
Final	548	527	540	544
Gain	179	172	174	178
Daily Gain	1.51 ± .15	1.45± .19	1.46± .21	1.50± .20
Average Daily Ration, kg				
Supplement	.88	.97	.89	.87
Grain Mix	8.78	8.70	8.69	8.66
Chopped Hay	1.79	2.0	1.93	1.82
Salt	.05	.05	.05	.05
Mineral		.08		.13
Average Daily Ration, kg	11.5	11.8	11.6	11.5
Kg Feed Per Kg of Gain	7.68± .75	8.24± 1.2	8.10± 1.5	7.12± .95

[a]Free-choice mineral

[b]As-fed basis

.6 percent ration calcium level did consume .05 kg/head/day more of the free-choice mineral than did the steers that were fed the .3 percent calcium treatment.

The daily calcium and phosphorus intake from the finishing ration and fecal pH, fecal alkalinity, and fecal starch content are shown in table 12. The daily calcium intake for all treatment groups except for cattle fed the .3 percent calcium level with no free-choice mineral, was much greater than the minimum of 22 to 28 g/head/day recommended by the National Research Council (NRC, 1976). All of the calcium-to-phosphorus ratios would be considered to be within a range not detrimental to performance (Beeson et al., 1975). It appeared that the cattle fed the .3 percent calcium level with free-choice mineral consumed sufficient mineral to equal approximately (50 versus 47 g.) the daily calcium intake of cattle fed the .6 percent calcium level with no free-choice mineral. Theuninck et al. (1977) would possibly interpret this to mean that the cattle fed the .3 percent level of calcium were fed a slightly calcium deficient ration and therefore consumed the free-choice mineral to make-up this calcium deficit.

There were no significant differences ($P > .05$) found among treatments in fecal pH, fecal alkalinity, or fecal starch content, but there was a wide variation among animals for these three variables. Regression analysis indicated there was no significant relationship

Table 12. Average Daily Calcium and Phosphorus Intake From the Finishing Ration, With Fecal pH, Fecal Alkalinity, and Fecal Starch Content - Trial I.

Lot No.	5 & 9	6 & 10	7 & 11	8 & 12
Treatment (% Ca)	.3	.3 + fcm.	.6	.6 + fcm.
MSU Formula #	780	780 + 802	803	803 + 802
No. Head	16	14	16	16
Calcium Intake Per Day, g.				
Grain Mix	14.9	14.8	14.8	14.7
Chopped Hay	5.9	6.6	6.3	6.0
Supplement	13.1	14.5	26.3	26.2
Free-Choice Mineral		14.1		21.2
Total Calcium Per Day	33.9	50.0	47.8	68.1
Total Phosphorus Per Day	32.7	39.5	37.3	41.8
Ca:P Ratio	1.0	1.3	1.3	1.6
Fecal pH	5.6 ± .29	5.9 ± .67	5.8 ±.39	5.9 ± .42
Fecal Alkalinity[a]	1532.8 ± 745	1964.7 ± 1384	1748.1 ± 1051	2232.8 ± 1412
% Fecal Starch[b]	5.5 ± 4.2	4.9 ± 2.6	4.8 ± 4.4	3.4 ± 1.7

[a]Expressed as milligrams of calcium carbonate per liter of sample.

[b]Expressed as a percent of the fecal dry matter.

($P > .05$) between treatment and fecal starch content. However, it should be noted that the feces of cattle fed the .6 percent calcium level with access to the free-choice mineral (68.1 g./head/day of Ca.) contained 38.2 percent less fecal starch than did the feces of cattle fed the .3 percent calcium level (33.9 g./head/day of Ca.) with no access to free-choice mineral. Fecal starch content was not found to be correlated ($P > .05$) with fecal pH. As might be expected fecal pH and fecal alkalinity were found to be positively correlated ($r = .63$; $P < .01$). The feces of the cattle fed the .6 percent calcium level with free-choice mineral did have a higher (2232.8 versus 1531.8 mg. $CaCO_3$ per liter of sample) alkalinity value than did the feces of cattle fed the .3 percent calcium level with no free-choice mineral. However, regression analysis indicated there was no significant ($P > .05$) relationship between fecal alkalinity and treatment.

Carcass data for cattle fed in finishing trial I are shown in table 13. There were no significant differences found among treatments in carcass merit. Steers fed the .6 percent calcium level with no free-choice mineral did have slightly less fat cover at the 12th rib than cattle fed the other calcium level treatments. There appeared to be no noticeable difference between treatments in the number of cattle found to have abscessed livers.

Table 13. Carcass Data for Steers Fed in Finishing Trial I.

Lot No.	5 & 9	6 & 10	7 & 11	8 & 12
Treatment (% Ca)	.3	.3 + fcm.	.6	.6 + fcm.
No. Head	16	14	16	16
Item				
Carcass Weight, kg	309.2	299.5	308.4	309.6
Dressing Percent	56.5 ± 1.3	56.7 ± 1.2	56.9 ± 1.4	56.8 ± 2.2
Ribeye Area, cm^2	79.3 ± 8.5	74.5 ± 8.9	77.4 ± 8.6	77.2 ± 8.6
Fat Cover, cm	1.07 ± .27	1.12 ± .39	.97 ± .28	1.12 ± .31
Quality Grade	10.2 ± 1.7	10.9 ± 1.7	10.7 ± 1.2	10.7 ± 1.1
Marbling Score	4.2 ± .58	4.5 ± .76	4.4 ± .63	4.4 ± .50
Abscessed Livers	3	2	3	4

[a]Hot carcass weight.

[b]Dressing percentage was calculated using the hot carcass weight.

[c]Quality grade score: 9, 10, 11 = good low, average and high.

[d]Marbling score: 3, 4, 5, = traces, slight and small.

Finishing Trial II

The feed lot performance results of cattle fed in trial II are shown in table 14. There were no significant differences ($P > .05$) found among treatments in daily gain, feed per gain, or daily ration intake. However, cattle fed the .3 percent calcium level required slightly less feed per kg. of gain than did the steers fed the other calcium treatments. The steers fed the .15 percent calcium treatment required 1.0, .5, and .6 kg. more feed per kg. of gain than did steers fed the .3, .6, and .9 percent calcium level treatments respectively. A greater number of steers were more noticeably foundered in the .15 percent calcium level treatment than in the other calcium treatments.

Ration palatibility was a problem at the beginning of trial II for the cattle fed the .9 percent calcium level treatment. The supplement (MSU Formula # 807) formulated for the .9 percent calcium treatment contained as much as 25.0 percent limestone. As a result of this high level of calcium the ration was very dusty and there appeared to be some settling of the limestone out of the ration. This palitability problem subsided as the amount of grain mix fed increased. Nicholson et al. (1960) also found that ration palatibility was a problem with cattle fed .9 percent calcium in the diet. In this study, palatibility was also found to improve as the trial progressed and the amount of grain fed increased.

Table 14. Average Daily Gain, Feed Per Gain, Daily Ration Intake, and the Incidence of Founder for Cattle Fed in Finishing Trial II.

Lot No.	17 & 21	18 & 22	19 & 23	20 & 24
Treatment (% Ca)	.15	.3	.6	.9
MSU Formula #	804	805	806	807
No. Head	12	9	12	12
Average Weights, kg				
Initial	279	273	273	275
Final	494	509	495	508
Gain	215	236	222	233
Daily Gain	1.12 ± .12	1.23 ± .17	1.15 ± .12	1.21 ± .11
Average Daily Ration, kg[a]				
Supplement	.81	.82	.84	.84
Grain Mix	7.22	6.95	7.03	7.33
Chopped Hay	1.67	1.66	1.64	1.63
Salt	.01	.01	.01	.01
Average Daily Feed, kg	9.7	9.4	9.5	9.8
Kg of Feed Per kg Gain	8.76 ± .99	7.81 ± 1.0	8.30 ± 1.0	8.17 ± .79
No. Foundered	5	2	3	2

[a]As-fed basis.

The incidence of bloat in trial II could partially be attributed to the low beet pulp content of the barley grain based finishing ration. This most likely reduced the crude fiber content of the grain mix. However, all cattle removed from test due to bloat were being fed the .3 percent calcium level treatment. None of the cattle fed the lower or higher levels of calcium were removed from test because of bloat. Increased feed intake and/or reduced saliva production may also explain the greater incidence of bloat for these cattle. The greater ash intake from the .6 and .9 percent calcium treatments may have prevented bloat from occurring in these treatments. Nicholson et al. (1960) noted when a high level of alfalfa ash (5.0 percent) was added to a diet fed to yearling steers and bulls the percentage of water in the rumen contents increased as did ration digestigibility.

During the early part of trial II, it was necessary to feed 350 mg./head/day of the antibiotic Aureomycin to all of the cattle for a period of 28 days. This recommended level of the antibiotic was fed with .91 kg. of ground barley grain per head per day to combat respiratory congestion present in most of the cattle which was probably brought on by stress caused by fluctuations in the weather. The barley-antibiotic premix was fed with the morning and afternoon feedings.

Daily calcium and phosphorus intake from the finishing ration

along with fecal pH and fecal starch content are shown in table 15. The daily calcium intake of 16 g. for cattle fed the .15 percent calcium level was less than the 22 to 28 g./head/day minimum level recommended by the National Research Council (NRC, 1976). The daily calcium intake of cattle fed the .3 percent calcium level was slightly above the recommended minimum intake, whereas cattle fed .6 and .9 percent calcium in the ration respectively consumed approximately 2.5 and 4.5 times the minimum recommended daily intake of calcium. The calcium-to-phosphorus ratio in the .15 percent calcium treatment (.5:1) would be considered by Wise et al. (1963) to be less than the minimum ratio needed for optimum performance. These workers found that Ca:P ratios less than 1:1 reduced the performance of Hereford calves.

Fecal pH for cattle receiving the .9 percent calcium level was significantly higher ($P < .01$) than the fecal pH (6.7 versus 6.1 and 6.2) of cattle fed the .15 and .3 percent calcium treatments. Fecal pH of cattle fed the .6 percent calcium treatment was not significantly different than the pH of the feces of cattle fed the two lower or the higher calcium level in the ration. Regression analysis indicated that 38 percent of the variation ($P < .01$) in fecal pH was due to a treatment effect. There was no significant difference found among treatments in the amount of starch appearing in the feces. However, it should be noted that the feces of cattle

Table 15. Average Daily Calcium and Phosphorus Intake From the Finishing Ration, With Fecal pH, and Fecal Starch Content - Trial II.

Lot No.	17 & 21	18 & 22	19 & 23	20 & 24
Treatment (% Ca)	.15	.3	.6	.9
MSU Formula #	804	805	806	807
No. Head	12	9	12	12
Calcium Intake Per Day, g,[a]				
Grain Mix	9.4	9.0	9.1	9.5
Chopped Hay	5.5	5.5	5.4	5.4
Supplement	1.0	22.3	47.2	98.1
Total Calcium Per Day	16.0	36.8	61.7	113.0
Total Phosphorus Per Day	32.0	31.0	31.6	32.4
Ca:P Ratio	.5	1.2	2.0	3.5
Fecal pH	6.1[b] ± .37	6.2[b] ± .38	6.5[bc] ± .41	6.7[c] ± .16
% Fecal Starch[d]	5.7 ± 3.2	7.1 ± 5.4	5.8 ± 2.4	5.1 ± 2.1

[a]As-fed basis.

[bc]Means in the same row with unlike superscripts are different (P >.05)

[d]Expressed as a percent of the fecal dry matter.

fed the .9 percent calcium level did have the least amount of starch of cattle fed in trial II. Fecal starch was found to be negatively correlated with ($r = -.38$; $P < .01$) fecal pH.

Carcass data for cattle fed in finishing trial II are shown in table 16. There were no significant differences found among treatmeants in carcass weight, dressing percent, ribeye area or fat cover at the 12th rib. Steers fed the .9 percent calcium level had the lowest quality grade score and marbling score in trial II. The quality grade for cattle fed the .9 percent calcium level was significantly lower than for cattle fed the .15 ($P < .01$) and .6 percent ($P < .05$) calcium levels. The marbling score for steers fed the .9 percent calcium treatment was significantly lower than the marbling score (4.8 versus 6.0) for cattle fed the .6 percent calcium level. There were no significant differences found between the .15, .3 and .9 percent calcium treatments in marbling score. Regression analysis indicated that 11 percent of the variation in quality grade ($P < .05$) and 12 percent of the variation in marbling score ($P < .05$) was due to a treatment effect.

Growing Trial III

The feedlot performance results of cattle fed in the high-roughage trial III are shown in table 17. There were no significant

Table 16. Carcass Data for Steers Fed in Finishing Trial II.

Lot No.	17 & 21	18 & 22	19 & 23	20 & 24
Treatment (% Ca)	.15	.3	.6	.9
No. Head	12	9	12	12
Item				
Carcass Weight, kg[a]	282.1	294.5	289.4	289.2
Dressing Percent[b]	58.7 ± .67	57.8 ± 1.2	57.3 ± 2.7	56.9 ± 1.9
Ribeye Area, cm^2	81.0 ± 9.3	75.3 ± 11.7	71.5 ± 7.7	77.8 ± 10.2
Fat Cover, cm	1.1 ± .38	1.3 ± .47	1.3 ± .47	1.2 ± .53
Quality Grade[c]	12.5^{e} ± .67	12.2^{ef} ± .83	12.4^{e} ± .51	11.5^{f} ± 1.2
Marbling Score[d]	5.9^{ef} ±1.0	5.9^{ef} ±1.4	6.0^{f} ± .85	4.8^{e} ± .94
Abscessed Livers	-	1	1	1

[a]Hot carcass weight.

[b]Dressing percentage was calculated using the hot carcass weight.

[c]Quality grade score: choice low, average and high = 12, 13 and 14.

[d]Marbling score: small, modest and moderate = 5, 6 and 7.

[ef]Means in the same row with unlike superscripts are different ($P < .05$).

Table 17. Average Daily Gain, Feed Per Gain, and Feed Intake Per Day - Trial III.

Lot No.	1	2	3	4
Treatment (% Ca)	.24	.60	1.0	1.9
MSU Formula #	804	805	806	807
No. Head	10	10	10	10
Average Weights, kg				
Initial	237	235	236	231
Final	277	275	279	270
Gain	40	40	43	39
Daily Gain	.71 ± .10	.71 ± .16	.75 ± .08	.70 ± .10
Average Daily Ration, kg[a]				
Supplement	.91	.91	.89	.91
Grain Mix	1.32	1.32	1.30	1.32
Chopped Hay	5.10	5.10	5.00	5.12
Average Daily Feed, kg	7.3	7.3	7.2	7.3
Kg. Feed Per Kg. of Gain	10.52 ± 1.6	11.00 ± 3.6	9.69 ± 1.0	10.75 ± 1.7

[a]As-fed basis.

differences ($P > .05$) found between treatments in average daily gain, feed per gain, or daily ration intake. However, cattle receiving the 1.0 percent calcium level gained slightly more and had better feed conversion than cattle receiving the other treatments.

Table 18 shows the average daily calcium and phosphorus intake from the high-roughage growing ration fed in trial III. The daily calcium intake of 19.7 g. for steers receiving the .24 percent calcium treatment was at the daily level recommended by the National Research Council. Calcium intake was approximately 2.1, 3.4, and 6.4 times the recommended level for the .6, 1.0, and 1.9 percent calcium treatments respectively. The calcium-to-phosphorus ratio of 8.1:1 for the 1.9 percent calcium treatment would be considered to be above the maximum ratio needed for optimum performance (Dowe et al., 1957).

Finishing Trial IV

The feedlot performance results for cattle fed in finishing trial IV are shown in table 19. Average daily gain, feed per gain, and daily ration intake were not found to be significantly different ($P > .05$) among treatments. However, steers receiving the .15 and .9 percent calcium levels required approximately 1.0 kg. more feed per kg. of gain than did steers fed the .3 and .6 percent calcium level treatments. It should also be noted that the cattle fed the

Table 18. Average Daily Calcium and Phosphorus Intake From the Growing Ration-Trial III.

Lot. No.	1	2	3	4
Treatment (% Ca)	.24	.60	1.0	1.9
No. Head	10	10	10	10
Calcium Intake Per Day, g.[a]				
Grain mix	1.7	1.7	1.7	1.7
Chopped Hay	16.8	16.8	16.5	16.9
Supplement	1.2	24.5	50.0	109.0
Total Ca./day, g.	19.7	43.0	68.2	127.6
Total P./day, g.	15.6	15.4	15.4	15.7
Ca:P ratio	1.3	2.3	4.4	8.1

[a]As-fed basis.

Table 19. Average Daily Gain, Feed Per Gain, Daily Ration Intake, and the Incidence of Founder for Cattle Fed in Finishing Trial IV.

Lot No.	1	2	3	4
Treatment (% Ca)	.15	.3	.6	.9
MSU Formula #	804	805	806	807
No. Head	9	9	10	10
Average Weights, kg				
Initial	279	278	279	270
Final	467	500	488	471
Gain	188	222	209	201
Daily Gain	1.06 ± .13	1.25 ± .05	1.17 ± .13	1.13 ± .29
Average Daily Ration, kg[a]				
Supplement	.91	.94	.89	.89
Gain Mix	7.13	7.54	7.10	6.99
Chopped Hay	1.72	1.76	1.68	1.65
Salt	.04	.02	.03	.02
Average Daily Feed, kg.	9.8	10.3	9.7	9.5
Kg. Feed Per Kg. of Gain	9.35 ± 1.4	8.24 ± .35	8.38 ± 1.0	9.17 ± 3.2
No. Foundered	4	3	3	2

[a]As-fed basis.

.3 percent calcium level consumed an average of .5 kg. more ration per day than steers fed the other calcium levels.

The daily calcium and phosphorus intake from the finishing ration along with fecal pH and fecal starch content are shown in table 20. The daily calcium intake and calcium-to-phosphorus ratio for steers fed the .15 percent calcium level were less than the recommended intake (22 to 28 g.) and ratio (2:1) by the National Research Council (NRC, 1976). Daily calcium intake for the steers fed the .3, .6, and .9 percent calcium levels respectively were 1.6, 2.6, and 4.8 times the recommended daily intake.

There was no significant difference found among treatments in the amount of starch present in the feces. However, as calcium intake increased, fecal starch did show a tendency to decrease. The feces of steers fed the .9 percent calcium level contained 30.0 percent less starch (4.6 versus 6.6 percent) than did the feces of cattle fed the .15 percent calcium treatment. There was only a 6.0 percent difference in fecal starch content between the feces of cattle fed the .3 and .6 percent calcium treatments. Regression analysis indicated that there was no significant relationship ($P > .05$) between treatment and fecal starch content.

Fecal pH for cattle fed the .9 percent calcium treatment was significantly higher (6.6 versus 6.2) than fecal pH of cattle fed the .15 percent calcium level. There was a trend noted of increased

Table 20. Average Daily Calcium and Phosphorus Intake From the Finishing Ration Along with Fecal pH and Fecal Starch Content - Trial IV.

Lot No.	1	2	3	4
Treatment (% Ca)	.15	.3	.6	.9
MSU Formula #	804	805	806	807
No. Head	9	9	10	10
Calcium Intake Per Day, g.[a]				
Grain Mix	9.3	9.8	9.2	9.1
Chopped Hay	5.7	5.8	5.6	5.4
Supplement	1.2	25.3	49.6	106.2
Total Calcium Per Day	16.2	41.0	64.4	120.7
Total Phosphorus Per Day	32.2	33.5	32.0	31.4
Ca:P Ratio	.5	1.2	2.0	3.8
Fecal pH	6.2[b] ± .22	6.3[bc] ± .40	6.5[bc] ± .24	6.6[c] ± .29
% Fecal Starch[d]	6.6 ± 5.1	6.1 ± 3.3	4.9 ± 2.2	4.6 ± 2.4

[a] As-fed basis.

[bc] Means in the same row with unlike superscripts are different ($P < .05$).

[d] Expressed as a percent of the fecal dry matter.

fecal pH with increased calcium intake. Regression analysis indicated that 24.0 percent of the variation in fecal pH ($P < .01$) was due to a treatment effect. Fecal starch content was not found to be correlated with ($P > .05$) fecal pH as in Trial II.

Carcass data for cattle fed in finishing trial IV are shown in table 21. None of the carcass characteristics listed in table 19 were found to be significantly different among treatments. However, steers fed the .3 percent and .6 percent levels of calcium tended to yield heavier carcasses (290 and 292 kg. versus 273 and 279 kg.) than cattle fed the .15 and .9 percent calcium treatments. In contrast to trial II, steers fed the .9 calcium level exhibited a higher and not lower marbling score than steers fed the other treatments. However, as in trial I, steers fed the .6 percent calcium level had less fat cover at the 12th rib than cattle fed the other treatments. Steers fed the .15 percent and .3 percent calcium levels showed a greater tendency to grade choice than did steers fed the .6 and .9 percent ration calcium levels.

Table 21. Carcass Data for Steers Fed in Finishing Trial IV.

Lot No.	1	2	3	4
Treatment (% Ca)	.15	.3	.6	.9
No. Head	9	9	10	10
Item				
Carcass Weight, kg[a]	273	290	292	279
Dressing Percent[b]	58.2 ± 1.9	58.0 ± 1.0	59.4 ± 1.7	59.8 ± 3.7
Ribeye Area, cm^2	65.7 ± 5.6	68.5 ± 3.1	70.3 ± 5.2	65.9 ± 4.3
Fat Cover, cm	1.3 ± .35	1.4 ± .30	1.1 ± .23	1.5 ± .64
Quality Grade[c]	12.1 ± .93	12.8 ± .67	10.7 ± 3.9	10.3 ± 5.5
Marbling Score[d]	5.2 ± .67	5.6 ± .53	5.0 ± .71	5.9 ± 1.1
Abscessed Livers	-	-	-	-

[a]Hot carcass weight.

[b]Dressing percentage was calculated using the hot carcass weight.

[c]Quality grade score: choice low, average and high = 12, 13 and 14.

[d]Marbling score: small, modest and moderate = 5, 6 and 7.

Chapter 5

DISCUSSION

Results of the four trials would seem to indicate there is no benefit to feeding increased levels of calcium in the diet of finishing cattle. However, it should be considered that in trials II and IV there was a slight (2.0 to 2.6 percent) reduction in the caloric density of the finishing ration as calcium level increased. Prokop (1980) considered this a factor when he fed either .47 or 1.14 percent calcium in the ration of 286 kg. finishing steers. In trial II the caloric density of the ration decreased from 1.91 Mcal. NE_m and 1.16 Mcal. NE_g per kg. of ration for the .15 percent calcium treatment to 1.88 Mcal. NE_m and 1.13 Mcal. NE_g per kg. of ration for the .9 percent calcium treatment. The caloric density of the ration in trial IV decreased from 1.91 Mcal NE_m and 1.15 Mcal. NE_g per kg. of ration to 1.86 Mcal. NE_m and 1.12 Mcal NE_g per kg. of ration for the .9 percent calcium level treatment. The caloric density of the finishing ration in trial I did not change, but remained constant at 1.85 Mcal. NE_m and 1.12 Mcal. NE_g per kg. of ration. Prokop (1980) concluded that if there was no advantage to feeding the higher level of calcium the slight caloric dilution of the ration with the higher calcium level would produce a lower response than the control group. Since he found no significant difference in gain or feed efficiency between the .47 and 1.14 percent calcium

treatments, he concluded that the higher calcium level did improve ration digestibility. The same conclusion could perhaps be made concerning trials II and IV, as there were no significant differences between treatments in daily gain, daily ration intake, or feed efficiency.

Consumption of the high-calcium, free-choice mineral in finishing trial I was sporadic throughout the trial. This is in agreement with Crawford et al. (1977) who also found consumption of a high-calcium, free-choice mineral to be sporadic in a trial conducted with 296 kg. yearling bulls. In addition, the workers also found that bulls fed a calcium deficient ration would consume sufficient high-calcium, free-choice mineral to equal the daily calcium intake of bulls fed a calcium adequate ration with no access to a free-choice mineral. Theuninck et al. (1977) also found that lambs fed a calcium deficient ration would consume more ($P < .05$) high-calcium, free-choice mineral than lambs fed a ration adequate in calcium. In trial I steers fed the .3 percent calcium level consumed sufficient free-choice mineral to enable daily calcium intake (50.0 g.) to equal approximately the daily calcium intake (47.8 g.) of cattle fed the .6 percent ration calcium level with no free-choice mineral. Had performance of cattle fed these two treatments been superior to that of the cattle fed the .3 percent calcium, or .6 percent calcium treatment with access to free-choice

mineral, it could possibly be concluded the cattle consumed the free-choice mineral in order to meet their calcium needs, and that .6 percent calcium in the ration is the optimum level. It should be noted that despite there being no significant difference between treatments, in consumption of the free-choice mineral, cattle fed the .6 percent calcium level consumed .05 kg./head/day more total mineral than did the cattle fed the .3 percent calcium level treatment.

In trials II and IV, cattle fed the .15 percent ration calcium levels required slightly more feed per kg. of gain than did cattle fed the other calcium treatments. This is in agreement with Theuninck (1977) who found that lambs fed a calcium deficient ration required more feed ($P < .05$) per kg. of gain than those fed a calcium adequate ration. The poorer feed efficiency exhibited by cattle fed the .15 percent calcium level in trials II and IV might be expected as this level is less than the minimum .3 percent calcium level recommended by the National Research Council (NRC, 1976). Varner and Woods (1972a) found cattle fed .21 percent calcium in the ration had poorer gain and feed efficiency than cattle fed either .31, .42 or .53 percent calcium.

In trial III, there was a slight advantage in gain and feed efficiency for cattle fed the 1.0 percent calcium level than for cattle fed the other calcium treatments. Cattle fed the 1.0 percent

calcium level consumed approximately three times (68.2 g.) the recommended daily intake (20 g.) of calcium (NRC, 1976). This could indicate the calcium requirements for growing calves may be higher than previously thought (Beeson et al., 1975). A longer growing period than 56 days would no doubt be needed to substantiate such an observation.

The lack of improved performance from the higher calcium levels contrasts results obtained by Wheeler et al. (1981a). They found that, with 263 kg. Simmental cross-bred steers, as ration calcium level increased from .35 to 1.05 percent calcium, daily gain and feed efficiency improved significantly. However, the lack of significant performance improvement is in agreement with Bushman et al. (1967) who found no difference in gain among steers fed .15, .3 or .6 percent calcium in the ration dry matter. Varner and Woods (1972a) found that gain and feed efficiency were not improved when feeding finishing steers calcium levels greater than .42 percent in the ration dry matter. The lack of results may be due in part to differences in limestone characteristics as Noller (1978) would suggest. Hard calcitic limestone was used in these trials, whereas soft calcitic limestone has been found (Wheeler, 1981) to be more reactive. However, the limestone used in these trials was comparable in rate of reactivity to the soft limestone used by Wheeler et al. (1981a) in which performance was improved with increased ration calcium levels with finishing steers.

If indeed a more favorable pH is created in the small intestine for amylase activity by feeding higher levels of limestone, then perhaps benefits would have been realized if corn and not barley had been fed. In trials I, II and IV the average amount of starch appearing in the feces was 4.6, 5.8 and 5.5 percent of the fecal dry matter respectively. These values are much less than those reported by other workers. Wheeler and Noller (1977) have reported fecal starch values as great as 32.4 percent of the fecal dry matter with finishing cattle. Ferreira et al. (1980) found fecal starch values at 10.8 and 18.2 percent of the fecal dry matter with dairy heifers. Zinn et al. (1979) reported fecal starch values of 15.5 to 23.9 percent of the fecal dry matter for 289 kg. feedlot steers. The smaller amount of fecal starch reported in these trials may be due to the fact barley and not corn was fed. In the previously cited work corn was used as the energy concentrate in the ration. Cattle receiving corn would have greater quantities of starch presented to the small intestine to be degraded by the more efficient alpha amylase enzyme. This hypothesis is based upon the finding that barley is apparently degraded in the rumen more extensively than is corn (Kay et al. 1972; Watson et al., 1972a).

The fact fecal starch was not significantly reduced with increasing calcium intake is in contrast to the findings of Ferreira et al. (1980). They found fecal starch in dairy heifers to

decrease significantly from 16.7 to 12.3 percent of the fecal dry matter when ration calcium level was increased from .3 to .9 percent calcium. Wheeler and Noller (1977) found the percentage of starch in the fecal dry matter of 404 kg. cross-bred steers and heifers to decrease significantly from 32.4 to 9.2 percent when the ration calcium level was increased from .3 to .9 percent calcium. However, in trials I and IV the amount of starch appearing in the feces was 38 percent and 30 percent less respectively when comparing feces of cattle fed the highest calcium level treatment to those receiving the lowest level of calcium in the ration. In trial II, cattle fed the .9 percent calcium level had the lowest amount of fecal starch when compared to other cattle in the trial. This may indicate a tendency toward increased digestion of starch in the small intestine, but that the amounts of starch presented to this region were not sufficient to provide a significant energy contribution.

Even if starch digestion improved, it cannot be proven from our trials that the improvement in digestibility occurred in the region of the small intestine since digestion studies were not conducted. Wheeler et al. (1981a) found that starch digestibility increased an average of 5.0 percent in trials with finishing steers fed ration calcium levels from .35 to 1.05 percent calcium. Zinn and Owens (1980) found when 2.5 percent calcium carbonate was added to the finishing ration fed to 308 kg. Angus steers starch digestibility

increased 30 percent in the rumen and not in the small intestine. The workers concluded that smaller quantities of starch were naturally being found in the feces of cattle receiving the calcium carbonate because less starch was escaping the rumen undigested.

That fecal pH was increased significantly in trials II and IV is in agreement with Wheeler et al. (1981a) who found fecal pH to increase significantly an average of .54 units when 263 kg. Simmental cross-bred steers were fed diets ranging from .35 to 1.05 percent calcium in the ration dry matter. In trials II and IV fecal pH was increased .6 and .4 pH units respectively between the .15 and .9 percent ration calcium levels. Even though fecal pH was not increased in trial I, the feces of steers fed the highest calcium level treatment were more alkaline (2232.8 versus 1531.8 mg. $CaCO_3$ per liter of sample) than the feces of cattle fed the lowest calcium level treatment.

Only in trial II was fecal starch found to be negatively correlated ($P < .01$) with fecal pH. However, the correlation coefficient of $r = -.38$ was much smaller than coefficients obtained by Wheeler and Noller (1977). These workers found coefficients of $r = -.82$ and $-.92$ in two finishing trials conducted with cattle. The lack of correlation between fecal starch and fecal pH in trials I and IV agrees with results obtained by Zinn and Owens (1980). They found that when fecal pH increased the amount of starch digested

in the small intestine actually decreased ($r = .71$; $P > .05$) in 308 kg. Angus steers.

In trials I and IV cattle fed the .6 percent ration calcium level had slightly less (16 percent) fat cover at the 12th rib than cattle fed the other calcium treatments. Even though this difference was not significant in either trial, the results are in agreement with Bushman et al. (1967) who found that cattle fed .6 percent calcium in the ration had 19 percent less fat cover at the 12th rib than did cattle fed either .15 or .3 percent calcium in the ration. However, Wheeler et al. (1981a) found that cattle fed higher levels of calcium in the diet had greater fat cover at the 12th rib. These workers also found that cattle fed the higher calcium levels (.70 and 1.05 percent versus .35 percent calcium) had heavier carcass weights. Carcass weight was not found to be significantly different among treatments in finishing trials I, II or IV. In trial II, cattle fed the .9 percent calcium treatment had a lower marbling score ($P < .01$) and quality grade ($P < .05$) than cattle fed lower calcium levels. In contrast, Wheeler et al. (1981a) found quality grade and marbling score to increase with increased ration calcium level.

Blood samples were not taken during the trials as ration calcium level apparently has no effect on blood calcium level (Wise et al., 1963; Wheeler et al., 1981).

Feedlot performance did not seem to be affected by suboptimum or excessively high calcium to phosphorus ratios. In trials II and IV, Ca:P ratios for the .15 percent calcium treatment was .5:1. The Ca:P ratio for the 1.9 percent calcium treatment in trial III was 8.1:1. The fact that performance was not significantly affected by the extreme Ca:P ratios differs from observations of Wise et al. (1963) who found Ca:P ratios less than 1:1 reduced performance in Hereford calves, and Dowe et al. (1957) who found that Hereford calves did poorly on Ca:P ratios greater than 4.3:1.

Since the pH of the feces of cattle in trials II and IV was decreased, it can be assumed that the pH of the small intestine was also increased (Wheeler and Noller, 1977). Perhaps the effect of this increased pH on the population balance between indigenous and nonindigenous micro-organisms in the small intestine should be explored. Questions that may be considered include: is the growth inhibiting factor of a lower pH removed, and certain pathogenic species of bacteria (such as E. Coli; Salmonella, and Staphylococcus) allowed to flourish, or is the utilization of nutrients in the small intestine hampered or enhanced by a change in microbial population? A more acidic gastrointestinal tract in infants has been associated with reduced numbers of E. Coli, accompanied by fewer digestive disorders and greater numbers of lactobacillus bifidus organisms. Also, patients suffering from achlorhydria have been found to have a

more profuse growth of bacteria in the small intestine (Donaldson, 1964).

Should the production of methane from manure become a common and accepted practice, feeding limestone might help to provide a more ideal pH environment in the feces for the growth of methane producing bacteria. Some methanogenic bacteria are unable to grow at a pH less than 6.0, but thrive at a more neutral pH (Ljungdahl, 1979).

Chapter 6

SUMMARY AND CONCLUSION

The effects of supplying more or less than the minimum recommended level of .3 percent calcium in the ration dry matter for finishing steers was studied in four feeding trials. Daily gain, daily feed intake, feed per gain, free-choice mineral consumption, fecal pH, fecal alkalinity, fecal starch content, and carcass merit were measured in response to various ration calcium level treatments. Limestone was used as the source of calcium throughout the trials.

Unlike results obtained by Wheeler et al. (1981a), feedlot performance was not significantly ($P > .05$) improved with increased intake of calcium in the four trials, but fecal pH was significantly ($P < .05$) increased in two of the three finishing trials when calcium level was increased from .15 to .9 percent in the ration dry matter. Regression analysis indicated that 38 and 24 percent of the variation in fecal pH in trials II ($P < .01$) and IV ($P < .05$) was due to a treatment effect.

Fecal starch content did not differ significantly ($P > .05$) among treatments, but a trend of a reduced fecal starch content as ration calcium level increased was noted in two trials. Starch appearing in the fecal dry matter was 38 and 30 percent less in trials I and IV when comparing the feces of cattle fed the highest level of calcium to those fed the lowest. Only in one trial was

fecal starch content found to be negatively correlated ($P < .01$; $r = -.38$) with fecal pH.

In one trial only were carcass traits found to differ significantly ($P < .05$) among the four calcium treatments. Cattle that were fed the .9 percent calcium level had the lowest marbling score ($P < .01$) and quality grade score ($P < .05$) of all cattle in the trial.

Daily consumption of free-choice mineral did not differ significantly ($P > .05$) between cattle fed the .3 and .6 percent calcium levels. However, cattle fed the .6 percent calcium level did consume .05 kg./head/day more of the mineral than did cattle receiving the .3 percent calcium treatment. Cattle fed the .3 percent calcium treatment consumed sufficient free-choice mineral to enable their daily calcium intake (50 g.) to equal approximately the daily intake (47.8 g.) of cattle fed the .6 percent calcium treatment with no access to free-choice mineral.

Lack of obvious benefits in these trials of feeding higher calcium levels to feedlot cattle may be due in part to the characteristics associated with the source of calcium. Noller (1978) suggested that source, particle size, chemical properties and physical properties will vary among limestones and influence their effectiveness as a buffer in the small intestine. However, the reactivity rate of limestone used in these trials had similar reactivity

(T_{50} 69 versus 60 seconds) to the limestone used by Wheeler (1979) who found that gain and feed efficiency improved with finishing cattle fed higher levels of calcium.

Even though no significant differences were noted among treatments, calcium intake did appear to have some influence on fecal starch content in these trials. It cannot be ignored that in two of the three finishing trials a trend of reduced fecal starch content was noted as calcium intake increased. Also, in all three of the finishing trials the feces of cattle fed the highest calcium level contained the least amount of starch when compared to the feces of cattle fed lower calcium levels.

If the activity of alpha amylase was improved in these trials there may not have been sufficient starch presented to the small intestine from the barley grain based rations to make a significant energy contribution to the animal. Perhaps benefits from feeding the higher levels of calcium would have been realized if corn and not barley had been fed as the energy concentrate. This hypothesis is based upon the fact corn starch is not degraded in the rumen as extensively as is starch from barley grain (Kay et al., 1972a; Watson et al., 1972a; McCullough, 1973). The result of feeding corn and not barley would be more starch presented to the small intestine to be acted upon by the alpha amylase enzyme, theoretically more efficient due to the buffering effect of the limestone.

APPENDIX

NOTE: The analysis of variance of data is shown in the Appendix only if significant or near significant differences were detected among treatments, or if a trend was noted.

APPENDIX TABLE 1. Analysis of Variance for Fecal Starch Content, Finishing Trial I.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Main Effects				
Replication	1	16.95	1.371	.248
Treatment	3	11.665	.943	.427
Within Treatment	47	12.364		
Total	51	12.333		

APPENDIX TABLE 2. Analysis of Variance for Fecal Alkalinity, Finishing Trial I.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Main Effects				
Replication	1	646978.266	.465	.499
Treatment	3	1233538.750	.886	.455
Within Treatment	51	1392775.620		
Total	55	1374287.370		

APPENDIX TABLE 3. Analysis of Variance for High-Calcium, Free-Choice Mineral Consumption, Finishing Trial I.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Between Treatment	1	.0025	3.125	.2191
Within Treatment	2	.0008		
Total	3	.00136		

APPENDIX TABLE 4. Analysis of Variance for Fecal pH, Finishing Trial II

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Main Effects				
Replication	1	.069	.577	.452
Treatment	3	.885	7.411	.000
Within Treatment	40	.119		
Total	44	.170		

APPENDIX TABLE 5. Analysis of Variance for Quality Grade, Finishing Trial II

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Main Effects				
Replication	1	7.041	12.062	.001
Treatment	3	2.056	3.522	.023
Within Treatment	40	.584		
Total	44	.831		

APPENDIX TABLE 6. Analysis of Variance for Dressing Percentage, Finishing Trial II

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Main Effects				
Replication	1	.212	.064	.801
Treatment	3	7.568	2.286	.093
Within Treatment	40	3.311		
Total	44	3.531		

APPENDIX TABLE 7. Analysis of Variance for Marbling Score, Finishing Trial II

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Main Effects				
Replication	1	2.278	2.211	.145
Treatment	3	3.577	3.474	.025
Within Treatment	40	1.030		
Total	44	1.234		

APPENDIX TABLE 8. Analysis of Variance for Fecal pH, Finishing Trial IV

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Between Treatment	3	.339	3.923	.017
Within Treatment	34	.086		
Total	37	.107		

APPENDIX TABLE 9. Analysis of Variance for Fecal Starch Content, Finishing Trial IV

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Between Treatment	3	7.858	.708	.554
Within Treatment	33	11.104		
Total	36	10.833		

APPENDIX TABLE 10. Analysis of Variance for Carcass Weight, Finishing Trial IV

Source of Variation	Degrees of Freedom	Mean Square	F	Significance of F
Between Treatment	3	734.202	1.237	.314
Within Treatment	33	593.654		
Total	36	606.431		

LITERATURE CITED

LITERATURE CITED

Anderson, P. E., J. T. Reid, M. J. Anderson and J. W. Stroud. 1959. Influence of level of intake upon the apparent digestibility of forages and mixed diets by ruminants. J. Anim. Sci. 18:1299.

AMSA. 1977. Recommended Procedures for Beef Carcass Evaluation and Carcass Contests (2nd Ed.) American Meat Science Association. Chicago, Illinois.

AOAC. 1970. Offical Methods of Analysis (11th Ed.). Association of Offical Agricultural Chemists. Washington, D.C.

APHA. 1971. Standard Methods for the Examination of Water and Waste Water. (13th Ed.) M. J. Taras, A. E. Greenberg, R. D. Hoak, and M. C. Rand, Editors. American Public Health Association. Washington, D.C.

Armstrong, D. G. and D. E. Beever. 1969. Post-abomasal digestion of carbohydrate in the adult ruminant. Proc. Nutr. Soc. 28:121.

Armstrong, D. G., K. L. Blaxter and N. McC. Graham. 1960. Fat synthesis from glucose by sheep. Proc. Nutr. Soc. 19;xxxi.

Ash, R. W. 1961. Acid secretion by the abomasum and its relation to the flow of food material in the sheep. J. Physiol. 156:93.

Baily, C. B. 1961. Saliva secretion and its relation to feeding in cattle. The rate of secretion of mixed saliva in the cow during eating, with an estimate of the magnitude of total daily secretion of mixed saliva. Brit. J. Nutr. 15:443.

Baily, C. B. and C. C. Balch. 1961. Saliva secretion and its relation to feeding in cattle. 2. The composition and rate of secretion of mixed saliva in the cow during rest. Brit. J. Nutr. 15:383.

Balch, C. C. 1959. Observations on the act of eating in cattle. Brit. J. Nutr. 11:330.

Balch, D. A. and S. J. Rowland. 1957. Volatile fatty acids and lactic acid in the rumen of dairy cows receiving a variety of diets. Brit. J. Nutr. 11:288.

Baldwin, R. L. 1965. Pathways of carbohydrate metabolism in the rumen. In. Digestive Physiology of the Ruminant. Washington - Butterworths.

Banks, N. and C. T. Greenwood. 1975. Starch and its Components. Edinburgh University Press, Edinburgh, Great Britain.

Bartley, E. E. 1975. Bovine Saliva : production and function. In. Buffers in Ruminant Physiology and Metabolism. Myron S. Weinberg and A. Leonard Sheffner (Eds.) Church and Dwight, Inc., New York, New York.

Bath, I. H. and J. A. F. Rook. 1963. The evaluation of cattle foods and diets in terms of the ruminal concentration of volatile fatty acids. 1. The effects of level of intake, frequency of feeding, the ratio of hay to concentrates in the diet, and of supplementary feeds. J. Agri. Sci. 61:341.

Bender, M. L. and L. J. Brubacker. 1973. Catalysis and Enzyme Action. McGraw Hill Book Co., New York.

Ben-Ghedalia, D., H. TaGari and A. Bondi. 1974. Protein digestion in the intestine of the sheep. Brit. J. Nutr. 31:115.

Beeson, W. M., T. W. Perry, N. L. Jacobson, K. D. Wiggers and G. N. Jacobson. 1975. Calcium in Beef and Dairy Nutrition. National Feed Ingredients Assoc., West Des Moines, Iowa.

Beever, D. E., J. F. Coehlo da Silva and D. G. Armstrong. 1970. The effect of processing maize on its digestion in sheep. Proc. Nutr. Soc. 29:43A.

Blaxter, K. L. 1962. The utilization of the energy of the end-products of the digestion process. In. The Energy Metabolism of Ruminants. C. C. Thomas, Springfield, Illinois.

Blaxter, K. L. and N. McC. Graham. 1956. The effect of the grinding and cubing process on the utilization of the energy of dried grass. J. Agr. Sci. 47:207.

Blaxter, K. L., N. McC. Graham and F. W. Wainman. Some observations on the digestibility of food by sheep, and related problems. Brit. J. Nutr. 10:69.

Blizzard, W. L. 1939. The value of adding ground limestone to a calf fattening ration of ground shelled corn, cottonseed meal and prairie hay. Okla. Agr. Exp. Station Bulletin No. 237. pg. 11.

Bohinski, R. C. 1979. Enzymes. In. Modern Concepts in Biochemistry. (3rd Ed.) Allyn and Bacon, Inc., Boston, Mass.

Borgstrom, B., A. Dahlquist, G. Lundh and J. Sjovall. 1957. Studies of intestinal digestion and absorption in the human. J. Clin. Invest. 36:1521.

Braithwaite, G. D. and S. H. Riazuddin. 1971. The effect of age and level of dietary calcium intake on metabolism in sheep. Brit. J. Nutr. 26:215.

Briggs, P. K., J. P. Hogan and R. L. Reid. 1957. The effect of VFA, lactic acid, and ammonia on rumen pH in sheep. Australian J. Agr. Res. 8:674.

Bushman, D. H., L. B. Embry, R. M. Luther and R. J. Emerick. 1967. Calcium and fat relationship in cattle fed all concentrate rations. J. Anim. Sci. 26:1486 (Abstr.)

Church, D. C. 1969. Rumen fermentation of natural feedstuffs. In. Digestive Physiology and Nutrition of Ruminants. Vol. 1, pg. 247. D. C. Church, Corvallis, Washington.

Clark and Collip. 1925. Modification of Kramer-Tisdall method for calcium determination. Hawks' Physiological Chemistry (14th Ed.). B. L. Oser, Editor, McGraw-Hill, New York. pg. 1133.

Clary, J. J., G. E. Mitchell, Jr. and C. O. Little. 1967. Adaptation of sheep pancreatic secretion to dietary change. J. Anim. Sci. 26:917 (Abstr.)

Colovos, N. F., H. A. Keener and H. A. Davis. 1955. The effects of pulverized limestone and dicalcium phosphate on the nutritive value of dairy cattle feed. J. Dairy Sci. 38:627.

Crawford, D. W., J. C. Meiske and R. D. Goodrich. 1977. Free choice minerals for cattle fed calcium adequate or calcium deficient rations. Minnesota Cattle Feeders Report, No. B-225. The University of Minnesota.

Delay, R. L. 1972. Bovine duodenal amylase activity. PhD Dissertation. Colorado State University, Fort Collins, Colorado.

Dollar, A. M. and J. W. G. Porter. 1957. Utilization of carbohydrates by the young calf. Nature. 179:1299.

Dowe, T. W., J. Matsushima and V. H. Arthaud. 1957. The effects of adequate and excessive calcium when fed with adequate phosphorus in growing rations for beef calves. J. Anim. Sci. 16:811.

Donaldson, R. M. 1964. Normal bacterial populations of the intestine and their relation to intestinal function. New England Journal of Medicine. 270:131.

Emery, R. S., L. D. Brown and J. W. Thomas. 1964. Effects of sodium and calcium carbonates on milk production and composition of milk, blood and rumen contents of cows fed grain ad libitum with restricted roughage. J. Dairy Sci. 47:1325.

Emmanuel, B., M. J. Lawlor and D. M. McAleese. 1969. The rumen buffering system of sheep fed pelleted roughage-concentrate rations. Brit. J. Nutr. 23:805.

Esdale, W. J. and L. D. Satter. 1972. Manipulation of ruminal fermentation. IV. Effect of altering ruminal pH on volatile fatty acid production. J. Dairy Sci. 55:964.

Everett, W. W., and J. F. Foster. 1959. The conformation of amylase in solution. J. Amer. Chem. Soc. 81:3464.

Ewing, P. V. and F. H. Smith. 1917. A study of the rate of passage of food residues through the steer and its influence on digestion coefficients. J. Agr. Res. 10:55.

Ferreira, J. J., C. H. Noller, R. B. Keyser and T. S. Stewart. 1980. Influence of dietary calcium and protein on fecal pH, consistency, and rate of passage in dairy cattle. J. Dairy Sci. 63:1091.

Fiske, C. H. and Y. Sabbarow. 1925. Phosphorus determination. J. Biol. Sci. 66:375.

French, D. 1973. Chemical and physical properties of starch. J. Anim. Sci. 37:1048.

Galyean, M. L., D. G. Wagner and R. R. Johnson. 1976. Site and extent of starch digestion in steers fed processed corn rations. J. Anim. Sci. 43:1088.

Gray, G. M. 1970. Carbohydrate digestion and absorption. Gastroenterology. 58:96.

Hale, W. H. 1973. Influence of processing on the utilization of grains (starch) by ruminants. J. Anim. Sci. 37:1075.

Harrison, F. A. and K. J. Hill. 1962. Digestive secretions and flow of digesta along the duodenum of sheep. J. Physiol. 162:225.

Heald, P. J. 1951. The assessment of glucose containing substances in rumen micro-organisms during a digestion cycle in sheep. Brit. J. Nutr. 5:84.

Hele, M. P. 1950. Phosphorylation and absorption of sugars in the rat. Nature. 166:786.

Hembry, F. G., M. C. Bell and R. F. Hall. 1967. Intestinal carbohydrase activity and carbohydrate utilization in mature sheep. J. Nutr. 93:175.

Henschel, M. J. W. B. Hill and J. W. G. Porter. 1963. Carbohydrate digestion in the small intestine of the young steer. Proc. Nutr. Soc. 22:V.

Hill, K. J. 1970. Digestion in the small intestine. In M. J. Swenson (Ed.) Dukes' Physiology of Domestic Animals. Compstock Publishing Associates, Ithaca and London.

Hodge, J. E., and B. T. Hofreiter. 1962. Determination of reducing sugars and carbohydrates. Page 380. In Methods in Carbohydrate Chemistry. Vol. I, R. L. Whistler and M. L. Wolfrom, Editors, Academic Press, New York.

Holmes, J. H. G., M. J. Drennan and W. N. Garrett. 1970. Digestion of steam processed milo by ruminants. J. Anim. Sci. 31:409.

Huber, J. T., N. L. Jacobson, A. D. McGilliard and R. S. Allen. 1961. Utilization of carbohydrates introduced directly into the omaso-abomasal area of the stomach of cattle of various ages. J. Dairy Sci. 44:321.

Huber, J. T., R. S. Emery, J. W. Thomas and I. M. Yousef. 1969. Milk fat synthesis on restricted roughage rations containing whey, sodium bicarbonate and magnesium oxide. J. Dairy Sci. 52:54.

Hungate, R. E. 1966. The Rumen and Its Microbes. Academic Press., New York and London.

Karr, M. R., C. O. Little and G. E. Mitchell, Jr. 1966. Starch disappearance from different segments of the digestive tract of steers. J. Anim. Sci. 25:652.

Kay, R. N. B. 1959. The rate of flow and composition of various salivary secretions in sheep and calves. J. Physiol. 150:515.

Kay, R. N. B. 1969. Digestion in the abomasum and intestine of the ruminant. Digestion of protein in the intestine of adult ruminants. Proc. Nutr. Soc. 28:140.

Kay, R. N. B. and P. N. Hobson. 1963. The physiology of the rumen. Part 2. Rumen microbiology. J. Dairy Res. 30:261.

Kay, M., N. A. MacLeod and A. Pavlicevic. 1972. The value of different cereals in diets for growing steers. Proc. Nutr. Soc. 31:57A.

Keller, P. J., E. Cohen and H. Neurath. 1958. The proteins of bovine pancreatic juice. J. Biol. Chem. 233:344.

Kern, D. L., L. L. Slyter, E. C. Leffel, J. M. Weaver and R. R. Oltjen. 1974. Ponies vs. steers: microbial and chemical characteristics of intestinal ingesta. J. Anim. Sci. 38:559.

King, K. W. and W. E. C. Moore. 1957. Density and size as factors affecting passage rate of ingesta in the bovine and human digestive tracts. J. Dairy Sci. 40:528.

Larsen, H. J., G. E. Stoddard, N. L. Jacobson and R. S. Allen. 1956. Digestion and absorption of various carbohydrates posterior to the rumino-reticular area of the young bovine. J. Anim. Sci. 15:473.

Little, C. O., G. E. Mitchell and C. M. Reitnour. 1968. Postruminal digestion of corn starch in steers. J. Anim. Sci. 27:790.

Ljungdahl, L. G. 1979. Physiology of thermophilic bacteria. In Advances in Microbial Physiology. Vol. 19. Edited by A. H. Rose and J. Gareth Morris. Copyright 1979. Academic Press, Inc., New York, New York.

Luther, R. and A. Trenkle. 1967. Ruminal acid production in lambs fed pelleted diets containing different levels of concentrates. J. Anim. Sci. 26:590.

MacLeod, N. A., A. MacDearmid and M. Kay. 1972. A note on the use of field beans for growing cattle. Anim. Prod. 14:111.

Macrae, J. C. and D. G. Armstrong. 1969. Studies on intestinal digestion in the sheep. Digestion of some carbohydrate constituents in hay, cereal and hay-cereal rations. Brit. J. Nutr. 23:377.

McCullough, M. W. 1973. Effects of corn processing and roughage level on steer performance and gastroenteric starch disappearance. Ph.D. Dissertation. Colorado State University, Fort Collins, Colorado.

McDonald, I. W. 1969. Physiology of digestion, absorption and metabolism in the ruminant. In. D. Cuthbertson (Ed.) The Science of Nutrition of Farm Livestock. Part I. Vol. 17. Pergamon Press.

McGinty, D. D. and J. K. Riggs. 1968. Variation in digestibility of sorghum grain varieties. J. Anim. Sci. 27:1170.

McManus, W. R. 1959. Relationship between pH and volatile fatty acid and diversion of saliva from the actively fermenting rumen of sheep. Nature. 184:1572.

McManus, W. R. 1962. Studies on the relationship of saliva to rumen function of sheep on low feed intakes. Australian J. Agr. Res. 13:907.

McNeill, J. W., G. D. Potter and J. K. Riggs. 1971. Ruminal and postruminal carbohydrate utilization in steers fed processed sorghum grain. J. Anim. Sci. 33:1371.

Metzler, D. E. 1977. Biochemistry: The Chemical Reactions of Living Cells. Academic Press, New York and London.

Meyer, R. M., E. E. Bartley, J. L. Morril and W. E. Stewart. 1964. Salivation in cattle. I. Feed and animal factors affecting salivation and its relation to bloat. J. Dairy Sci. 47:1339.

Miller, J. K., B. R. Moss and W. F. Byrne. 1969. Evaluation of methods for introducing materials directing into the abomasum of yearling cattle. J. Dairy Sci. 52:1643.

Miller, J. K., B. R. Moss and W. F. Byrne. 1971. Distribution of cerium in the digestive tract of the calf according to time after dosing. J. Dairy Sci. 54:497.

Mould, D. L. and G. J. Thomas. 1958. The Enzymic degradation of starch by holotrich protozoa from sheep rumen. Biochem. J. 69:327.

Muller, L. D. and L. H. Kilmer. 1979. Sodium Bicarbonate in Dairy Nutrition. The National Feed Ingredients Association, West Des Moines, Iowa.

Mumford, H. W. 1928. Feeding rate determines speed of feeds passage. Illinois Agricultural Experiment Station Report No. 41, pg. 117.

Nicholson, J. W. G. and H. M. Cunningham. 1961. The addition of buffers to ruminant rations. I. Effect of weight gains, efficiency of gains and consumption of rations with and without roughage. Can. J. Anim. Sci. 41:134.

Nicholson, J. W. G. and J. D. Sutton. 1969. The effect of diet composition and level of feeding on digestion in the stomach and intestines of sheep. Brit. J. Nutr. 23:585.

Nicholson, J. W. G., J. K. Loosli and R. G. Warner. 1960. Influence of mineral supplements on the growth of calves, digestibility of the rations and intra-ruminal environment. J. Anim. Sci. 19:1071.

Nicholson, J. W. G., H. M. Cunningham and D. W. Friend. 1963. The addition of buffers to ruminant rations. IV. The effect of additions of sodium bicarbonate, sodium propionate, limestone and cod liver oil on intra-rumen environment. Can. J. Anim. Sci. 43:309.

Nie, N. H., C. H. Hull, J. G. Jenkinds, K. Steinbrenner and D. H. Bent. 1975. SPSS: Statistical Package for the Social Sciences. (2nd Ed.) McGraw-Hill, Inc., New York.

Noller, C. H. 1978. New developments in ruminant nutrition: the lower gastrointestinal tract. Proc. Maryland Nutr. Conf., pg. 67.

Noller, C. H. 1980. Buffers in diets of cattle. Proceedings of the Purdue Feed Industry Conference. February, 1980.

Noller, C. H., J. L. White and W. E. Wheeler. 1980. Characterization of cement kiln dusts and animal response. J. Dairy Sci. 63:1947.

N.R.C. 1976. Nutrient Requirements of Domestic Animals. No. 2. Nutrient Requirements of Beef Cattle. Fifth Revised Ed. National Academy of Sciences, Washington, D.C.

Orskov, E. R. and C. Fraser. 1968. Dietary factors influencing starch disappearance in various parts of the alimentary tract and ceacal fermentation in early weaning lambs. Proc. Nutr. Soc. 27:37A.

Orskov, E. R. and C. Fraser. 1972. Effect on type of rumen fermentation and digestibility of feeding whole as opposed to processed barley to sheep. Proc. Nutr. Soc. 31:101A.

Orskov, E. R., C. Fraser and R. N. B. Kay. 1968. Dietary factors influencing the digestion of starch in the rumen and small and large intestine of early weaned lambs. Brit. J. Nutr. 23:217.

Orskov, E. R., C. Fraser and I. McDonald. 1971a. Digestion of concentrates in sheep. 1. The effect of increasing the concentration of soya-bean meal in a barley diet on apparent disappearance of feed constituents along the digestive tract. Brit. J. Nutr. 26:477.

Orskov, E. R., C. Fraser, V. C. Mason and S. O. Mann. 1970. Influence of starch digestion in the large intestine of sheep on ceacal fermentation, ceacal microflora and feacal nitrogen excretion. Brit. J. Nutr. 24:671.

Oser, B. L. 1965. Carbohydrates. In Hawks Physiological Chemistry. (14th Ed.) McGraw-Hill Inc., New York, New York.

Perry, T. W., K. S. Hendrix and R. C. Peterson. 1980. Elevated levels of calcium for growing beef cattle. Proceedings from the Indiana Beef Cattle Day. Purdue University, West Lafayette, Indiana. pg. 5.

Phillipson, A. T. 1942. The fluctuation of pH and organic acids in the rumen of the sheep. J. Exp. Biol. 19:186.

Phillipson, A. T. 1977. Ruminant digestion. In M. J. Swenson (Ed.) Dukes' Physiology of Domestic Animals. Compstock Publishing Associates. Ithaca and London.

Phillipson, A. T. and R. A. McAnally. 1942. Studies on the fate of carbohydrates in the rumen of sheep. J. Exp. Biol. 19:199.

Poutiainen, E. K., C. B. Lansdale and G. E. Outen. 1971. The growth of young cattle fed on dried grass alone and with barley. 2. Effects of digestion. Anim. Prod. 13:473.

Prokop, M. 1980. The effect of floured limestone in cattle finishing rations. Proceedings of the California Cattle Feeders Day, University of California, Monterey, California, pg. 51.

Putnam, P. A., R. Lehmann and R. E. Davis. 1966. Feed intake and salivary secretion by steers. J. Anim. Sci. 25:817.

Putnam, P. A., D. A. Yarns and R. E. Davis. 1966. Effect of pelleting rations and hay grain ratio on salivary secretion and ruminal characteristics of steers. J. Anim. Sci. 25:1177.

Rhodes, R. W. and W. Woods, 1962. Volatile fatty acid measurements on the rumen contents of lambs fed rations of various physical form. J. Anim. Sci. 21:484.

Robyt, J. F. and D. French. 1969. The action of porcine pancreatic alpha amylase in relation to the substrate binding site of the enzyme. J. Biol. Chem. 245:3917.

Rodrique, C. B. and N. N. Allen. 1959. The effect of fine grinding of hay on ration digestibility, rate of passage and fat content of milk. Can. J. Anim. Sci. 40:23.

Rumsey, T. S., P. A. Putnam, J. Bond and R. R. Oltjen. 1970. Influence of level and type of diet on ruminal pH and VFA, respiratory rate and EKG patterns of steers. J. Anim. Sci. 31:608.

Shaw, J. C., W. L. Ensor, H. F. Tellechea and S. D. Lee. 1960. Relation of diet to rumen volatile fatty acids, digestibility, efficiency of gain and degree of unsaturation of barley fat in steers. J. Nutr. 71:203.

Siddons, R. C. 1968. Carbohydrase activities in the bovine digestive tract. Biochem. J. 108:839.

Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. University of Wisconsin Research Report # 41.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods. (6th Ed.) Iowa State College Press, Ames, Iowa.

Steinberg, W. H., H. H. Hutchins, P. G. Pick and J. S. Lazar. 1965. Automated technique for determining dissolution and reaction rate of antacids. I. Instrumentation and evaluation of antacid raw materials. J. Pharm. Sci. 54:625.

Sutton, J. D., A. D. McGilliard and N. L. Jacobson. 1963. Functional development of rumen mucosa. I. Absorptive ability. J. Anim. Sci. 46:426.

Taylor, R. B. 1958. Pancreatic secretion in the conscious sheep. J. Physiol. 143:81-82P.

Tauber, H. 1949. The Chemistry and Technology of Enzymes. pg. 81. John Wiley and Sons, Inc., New York, New York.

Teeter, R. G., F. N. Owens, J. E. Williams and Wendy Benton. 1980. Roughage-concentrate associate effects. 1980 Oklahoma Agricultural Experiment Station Report MP 107:156. Oklahoma State University, Stillwater, Oklahoma.

Thompson, J. T., N. W. Bradley and C. O. Little. 1964. Ruminal volatile fatty acid concentrations and performance of steers fed different levels and forms of hay and grain. J. Anim. Sci. 23:895. (Abstr.)

Thorlacius, S. O. and G. A. Lodge. 1973. Absorption of steam volatile fatty acids from the rumen of the cow as influenced by diet, buffers and pH. Can. J. Anim. Sci. 53:279.

Thornton, J. H., F. N. Owens, R. W. Fent and K. Poling. 1978. Buffers and high moisture corn digestion. Oklahoma State University, 1978 Oklahoma Experiment Station Research Report. pg. 73.

Topps, J. H., R. N. B. Kay and E. D. Goodall. 1968. Digestion of concentrate and of hay diets in the stomach and intestines of sheep. Brit. J. Nutr. 22:261.

Topps, J. H., R. N. B. Kay, E. D. Goodall, F. G. Whitelaw and R. S. Ried. 1969. Digestion of concentrate and of hay diets in the intestine of ruminants. 2. Young steers. Brit. J. Nutr. 22:281.

Trenkle, A. H. 1979. Sodium Bicarbonate in Beef Nutrition. Published by the National Feed Ingredients Association. West Des Moines, Iowa.

Tyrrell, H. F., P. W. Moe and R. R. Oltjen. 1972. Energetics of fattening heifers on a corn vs. barley ration. J. Anim. Sci. 35:277 (Abstr.).

Tucker, R. E., G. E. Mitchell, Jr. and C. O. Little. 1968. Ruminal and postruminal starch digestion in sheep. J. Anim. Sci. 27:824.

Uhart, B. A. and F. D. Carroll. 1967. Acidosis in beef steers. J. Anim. Sci. 26:1195.

Vallee, B. L., E. A. Stein, W. N. Sumerwell and E. H. Fischer. 1959. Metal content of alpha amylases of various origins. J. Biol. Chem. 234:2901.

Varner, L. W. and W. Woods. 1972a. Effect of calcium and starch additions upon ration digestibility by steers. J. Anim. Sci. 35:410.

Varner, L. W. and W. Woods. 1972b. Calcium levels in high grain beef cattle rations. J. Anim. Sci. 35:415.

Vetter, R. L. and F. B. Stifel. 1971. Enzyme activities of jejunal and rumen mucosa. J. Anim. Sci. 33:305.

Waldo, D. R. 1973. Extent and partition of cereal grain starch digestion in ruminants. J. Anim. Sci. 37:1062.

Walker, D. M. 1959. The development of the digestive system of the young animal. III. Carbohydrase enzyme development in the young lamb. J. Agr. Sci. 53:374.

Wass, W. M. 1965. The duct systems of the bovine and porcine pancreas. Am. J. Vet. Res. 26:267.

Watson, M. J., G. P. Savage and D. G. Armstrong. 1972a. Sites of disappearance of apparently digestible energy and apparently digestible nitrogen in the digestive tract of cows receiving dried grass-concentrate diets. Proc. Nutr. Soc. 31:98A.

Watson, M. J., G. P. Savage, I. Brown and D. G. Armstrong. 1972b. Sites of disappearance of apparently digestible cellulose and apparently digestible alpha-linked glucose polymers in the digestive tract of a cow receiving dried grass-concentrate diets. Proc. Nutr. Soc. 31:99A.

Weinberg, M. S. and Sheffner. 1976. Buffers in Ruminant Physiology and Metabolism. Church and Dwight Company Inc., New York, New York.

Weller, R. A. and F. V. Gray. 1954. The passage of starch through the stomach of the sheep. Brit. J. Nutr. 31:40.

Wheeler, W. E. 1979. Determine the effect of rate of reactivity of limestone buffer additions on the performance of beef steers fed high energy diets. Summary of Research, U. S. Meat Animal Research Center, Nutrition Research Unit, Clay Center, Nebraska.

Wheeler, W. E. 1980a. Gastrointestinal tract pH environment and the invluence of buffering materials on the performance of ruminants. J. Anim. Sci. 51:224.

Wheeler, W. E. 1980b. Effect of limestone buffers on digestibility of complete diets and on performance by dairy cows. J. Dairy Sci. 63:1848.

Wheeler, W. E. 1981. Buffering agents for ruminants. 1981 Proceedings of the Florida Nutrition Conference. The University of Florida, Gainesville, Florida.

Wheeler, W. E. and C. H. Noller. 1976a. Limestone buffers in complete mixed rations for dairy cattle. J. Dairy Sci. 59:1788.

Wheeler, W. E. and C. H. Noller. 1976b. Limestone buffers and rumin- and digestive tract pH. J. Anim. Sci. 42:1365 (Abstr.).

Wheeler, W. E. and C. H. Noller. 1977. Gastrointestinal tract pH and starch in feces of ruminants. J. Anim. Sci. 44:131.

Wheeler, W. E. and R. R. Oltjen. 1979. Cement kiln dust in complete diets for finishing steers and growing lambs. J. Anim. Sci. 48:658.

Wheeler, W. E., C. H. Noller and C. E. Coppock. 1975. Effect of forage to concentrate ratio in complete feeds and feed intake on digestion of starch by dairy cows. J. Dairy Sci. 58:1902.

Wheeler, W. E., C. H. Noller and R. S. Lowrey. 1976. Ruminant digestive tract pH and loss of starch in feces. J. Anim. Sci. 42:277 (Abstr.).

Wheeler, W. E., C. H. Noller and J. L. White. 1980a. Influence of limestone source on the performance of beef steers fed corn silage-corn grain based diets. Proc. 72nd Annual Meeting of the American Society of Animal Science. pg. 409.

Wheeler, W. E., C. H. Noller and J. L. White. 1980b. Variation in the performance of beef steers fed corn silage-corn grain based diets containing limestone of different geological types. Proc. 72nd Annual Meeting of the American Society of Animal Science. pg. 410.

Wheeler, W. E., C. H. Noller and J. L. White. 1981a. Effect of calcium and rate of reactivity of calcitic limestones on utiliziation of high concentrate diets by beef steers. J. Anim. Sci. 52:882.

Wheeler, W. E., C. H. Noller and J. L. White. 1981b. Influence of petrological type of limestone on utilization of high concentrate diets by beef steers. J. Anim. Sci. 53:231.

White, P., P. Handler and E. Smith. 1968. Enzymes II. Kinetics, inhibition, metabolic inhibitors, control of enzyme activity. In: Principles of Biochemistry. (4th Ed.) McGraw-Hill Inc. New York.

Wilson, A. D. and D. E. Tribe. 1963. The effect of diet on the secretion of parotid saliva by sheep. Australian J. Agri. Res. 14:670.

Wise, M. B., A. L. Ordoveza and E. R. Barrick. 1963. Influence of variations in dietary calcium:phosphorus ratio on performance and blood constituents of calves. J. Nutr. 79:79.

Yarns, D. A., P. A. Putnam and E. C. Leffel. 1965. Daily salivary secretion by beef steers. J. Anim. Sci. 24:173.

Zinn, R. A. and F. N. Owens. 1980. Personal communication.

Zinn, R. A. and F. N. Owens. 1980a. Influence of roughage level and feed intake on digestive function. Oklahoma Agricultural Experiment Station. 1980 Animal Science Research Report. MP-107:150. Oklahoma State University.

Zinn, R. A. and F. N. Owens. 1980b. Sodium, calcium and potassium salts for cattle fed high concentrate rations. Oklahoma Agricultural Experiment Station. 1980 Animal Science Research Report. MP-107:131. Oklahoma State University.

Zinn, R. A., D. R. Gill, F. N. Owens and K. B. Poling. 1979. Cement kiln dust trials. Oklahoma Agricultural Experiment Station. 1979 Animal Science Research Report, pg. 37. Oklahoma State University.

Dew, R. K.
Calcium levels in finishing cattle rations

DATE	ISSUED TO