THE EFFECT OF FATTY ACID SALTS UPON RUMEN DEVELOPMENT IN DAIRY CALVES

By

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THE EFFECT OF FATTY ACID SALTS UPON RUMEN

DEVELOPMENT IN DAIRY CALVES

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INTRODUCTION

During recent years, it has been shown that young dairy calves may be raised successfully using an early weaning system. However, this requires that calves subsist entirely on dry feed at an early age. The success of such a system of raising calves depends upon early rumen development and function.

The rumen of the newborn calf is nonfunctional, having a smooth epithelium with no prominent papillae, and the microbial population has not been established. In addition, the abomasum is nearly twice as large as the rumen and reticulum combined. The nutrient requirements for a newborn calf are similar to those of simple-stomach animals in that a dietary source of high quality protein and B-complex vitamins must be provided, since they can not be synthesized by newborn calves. Complex carbohydrates also can not be utilized efficiently by newborn calves.

Before the young calf can utilize dry feeds of plant origin, the rumen must undergo a considerable amount of development. The size or capacity must increase before any large amount of dry feed can be consumed and the microbial population which is responsible for the breakdown and synthesis of several compounds in the rumen must be established. In addition, the structure of the rumen must be developed. This includes the mucosal tissue with its papillae which are responsible for the absorption of nutrients directly from the rumen into the blood stream and the muscle tissue which is responsible for supporting and mixing the contents

of the rumen. The stimulus necessary for the development of the rumen does not come entirely from the physical nature of the feed, but is due partly to the volatile fatty acids which result from rumen fermentation.

The main objective of the present study was to obtain information concerning the effect which salts of fatty acids have upon rumen development when added to a calf starter ration. Information regarding the growth and well-being of early weaned dairy calves fed a ration containing fatty acid salts was also desired. The problem as to what relationship may exist between the composition of the calf starter and the onset of rumination in young dairy calves was also investigated.

LITERATURE REVIEW

Rumen Development

The rumen must be developed from several standpoints. The volume or capacity as well as the mucosal and muscle tissue must be developed. Development of the rumen is affected by the type of diet the young calf receives. Furthermore, during early life the esophageal groove affects rumen development by shunting liquid materials past the rumen into the abomasum.

Function of the Esophageal Groove. The function of the esophageal groove is related to the development of the rumen in young calves. Hegland et al. (14) and Smith (33) noted that the esophageal groove is functional during the early life of the young calf, enabling liquids to effectively by-pass the rumen and enter the abomasum. Hegland et al. (14) observed that when gelatin capsules of various sizes were administered to young calves with a liquid they passed directly to the abomasum, but when given alone they were deposited in the reticulum. The esophageal groove was thus found to be functional in the calves up to 13 weeks of age. However, Smith (33) reported that the esophageal groove remained functional up to 32 weeks of age. The amount of milk entering the rumen was estimated to be less than five per cent in the majority of cases. There was no increase in the quantities of milk entering the rumen with increasing age.

Mucosal Tissue. Several workers (2, 8, 9, 11, 23, 31, 37, 40) have observed that rumen papillae develop and grow in response to chemical rather than physical stimuli. These chemical stimuli are believed to be the end-products of rumen fermentation.

Brownlee (2) observed very little papillary development in calves fed whole milk from 1 to 12 weeks of age. However, when calves of the same age were fed milk plus hay, grass or concentrates for 12 weeks, an increasing degree of rumen papillary development was noted. Similar results were observed by Warner et al. (40) when calves were fed whole milk and hay or grain. They observed some papillae in milk-fed calves as early as 4 weeks of age, but in most all cases the papillae were less than 2 mm. in length and remained essentially unchanged during the first 16 weeks of life. The calves which were receiving hay or grain, or a combination of hay and grain, had a marked papillary development at 4 weeks of age, with the papillae approaching 10 mm. in length. These workers suggested that the development of rumen papillae may be stimulated by chemical entities which result from rumen fermentation.

Several workers (8, 9, 31) have administered solutions of fatty acid salts by the use of rumen cannulae to young calves in order to determine their effect upon papillary development. Flatt et al. (8) observed that a purified diet or a solution of fatty acid salts, with or without sponges, produced more rumen mucosa in young calves than plastic sponges, cellulose sponges, or rumen liquor. The mixture of fatty acid salts which they "fed" consisted of sodium acetate, sodium propionate, sodium butyrate, and sodium lactate in a ratio of 50:20:20:10, respectively. The calves on the purified diet had the most extensive development of papillae and were the only calves which had an appreciable development over the entire rumen

surface. The calves receiving the mixture of fatty acid salts had papillary development only in a small part of the dorsal cranial sac of the rumen. Administration of the fatty acid salts with sponges resulted in a higher percentage of mucosa than the fatty acid salts alone. This was believed to be due to the sponges acting as an absorbant and thus enabling the acids to remain in contact with the rumen wall for a longer period of time. They suggested that the concentration of volatile fatty acids in the rumen liquor was not sufficient to cause any papillary development.

Flatt et al. (9) administered a solution of fatty acid salts to young calves through a fistula and reported the solution did not stimulate papillary development which is in contradiction to their earlier report. Inert roughage materials, such as nylon bristles and plastic sponges, also failed to elict any papillary development. However, when calves were allowed to consume solid feed, such as hay and grain or rumen ingesta, a marked papillary development was observed. The solution of fatty acid salts consisted of the sodium salts of acetic, propionic, butyric and lactic acids in a ratio of 50:20:20:10, respectively, with the pH adjusted to either 6.0 or 6.7. The failure of the solution of fatty acid salts to stimulate papillary development was due to the use of insufficient quantities of the acids, and/or leakage, or movement of the solution to the lower digestive tract. They reported that most of the development of the rumen wall occurs in the mucosal layer rather than in the muscular layer. Newborn and milk-fed calves had 50 per cent or less mucosal tissue in the rumen wall, whereas calves fed a solid feed had 60 per cent or more mucosal tissue. The percentage of mucosa was higher for the calves which

had received a high level of fermentable dry matter intake than for those which received either a non-fermentable dry feed or liquid materials.

Sander et al. (31) found that solutions of sodium butyrate or sodium propionate stimulated more papillary development than solutions of sodium acetate, sodium chloride or glucose when administered to young calves through rumen cannulae. They found that sodium butyrate produced slightly more mucosal development than sodium propionate. The sodium acetate, sodium chloride, and glucose produced a very limited amount of mucosal development only in the ventral part of the dorsal cranial sac, whereas the sodium butyrate and sodium propionate gave an extensive amount of development over a larger area of the rumen.

Tamate et al. (35) administered solutions of fatty acids, fatty acid salts, or salt solutions to young calves through a stomach tube. Calves which received only whole milk manifested no papillary development whereas calves fed hay and grain, in addition to milk, had a distinct papillary development. Other treatments which resulted in very little papillary development were as follows: a mixture of 70 per cent acetic acid and 30 per cent propionic acid diluted 1:55 with water; butyric acid diluted 1:55 with water; sodium butyrate and sodium propionate, each diluted 1:10 with water and administered at the rate of 2 g./kg. of body weight per feeding; a mixture of 70 per cent potassium acetate and 30 per cent sodium propionate, diluted 1:9 with whole milk; 4 per cent carbonated water; or potassium and sodium chlorides (1:1) and potassium and sodium bicarbonates (1:1) as 2 per cent (w/v) in addition to milk. However, calves receiving the acids had fold-like structures in the ruminal mucosa and atypical papillae.

Milk containing fatty acids with a mineral mixture resulted in more rumen development than milk with only the mineral mixture when fed to

young calves by Loe et al. (21) for 13 weeks. However, milk plus the fatty acids with the mineral mix did not result in as much rumen development as when hay, grain, and milk were fed.

Vair et al. (37) found when young calves were fed 10 grams of sodium acetate, sodium propionate or sodium butyrate in a milk-replacer the total weight of the rumen tissue was greater than in calves receiving only whole milk. They also observed that sodium butyrate and sodium propionate stimulated more papillary development than sodium acetate.

Wing and Ammerman (44) observed the development of rumen papillae in steers which had received various diets from birth to 9 to 11 months of age. Steers which received milk plus minerals and vitamins from birth to 11 months of age, with one exception, manifested some fold-like structures in the mucosa, but essentially no normal papillae. However, steers which received hay and grain from birth to 9-11 months of age, with milk only during the first 60 days, had an extensive development of rumen papillae.

If an active rumen fermentation is not maintained, rumen papillae may disappear. When Harrison et al. (11) reversed 16-week old calves from either a high-roughage or a high-concentrate ration back to a whole milk diet rumen papillae disappeared. They suggested that mucosal and muscular development of the rumen are independent as evidenced by: (a) a more rapid retrogression of the reticulo-rumen mucosa than of the reticulo-rumen muscle, (b) an extensive muscular development in the absence of mucosal development when calves were fed shavings, and (c) a lower nitrogen percentage in well-developed mucosa than in muscle, when expressed on a fat-free dry matter basis.

Sinclair and Kunkel (32), in a study with feedlot lambs, found a significant correlation between the percentage of rumen mucosa and 114-day

weight gains. However, they stated mucosal development may not be independent of the underlying muscle tissue. Rate of gain was also significantly correlated with rumen weight, papillary length and papillary density. These results were interpreted by the authors as evidence that growth and development of the animal as a whole is related to and may be dependent upon rumen development.

Muscle Tissue. The amount of muscle and mucosa in the rumen will depend upon (a) the size of the rumen and (b) the specific growth of each tissue above that required to keep the wall intact (41). However, musclar development has been shown to be extensive in the absence of mucosal development. This was observed by Harrison et al. (11) when 16-week old calves were reversed from a high-roughage or a high-concentrate ration back to a whole milk diet. The rumen papillae disappeared whereas the muscle tissue remained constant. The calves which received hay had the greatest amount of muscular development followed respectively by the shavings, grain and milk-fed calves. The extensive deposition of muscle in the calves fed shavings suggest the muscle tissue developed in response to the work of the rumen which was necessary to support and knead its contents. Sander et al. (31) found no significant differences among treatments with respect to growth of rumen muscle when sodium acetate, sodium propionate, sodium butyrate, sodium chloride or glucose, in addition to milk, were administered to calves over an 11-week period.

Rumen Capacity. Warner et al. (40) suggest the weight and capacity of the various stomach compartments may change from birth to 4 weeks of age, irrespective of the type of ration calves receive. High-hay fed calves were observed by Warner et al. (41) to have larger rumens at 16 weeks of age than those receiving a high-concentrate diet. Calves which

were fed skim-milk plus shavings had no active fermentation in the rumen but the capacity was about equal to that found in the high-hay fed calves. It was stated that the amount of residual ingesta may be the primary factor in expanding the rumen. Therefore, they concluded that: (a) since hay leaves the rumen more slowly than concentrates, the increase in capacity from hay diets could be due to a "piling up" of the hay with the dead weight of the ingesta stretching the rumen downward; (b) the rumen expands in rough proportion to the weight of materials it must hold on a day-to-day basis; and (c) rumen capacity per unit of body weight increases 5 to 6 fold while the amount of dry rumen tissue per unit of body weight remains essentially constant.

Smith (33) found an increase in rumen volume up to 30 weeks of age in relation to body weight. A four-fold increase was observed between 4 to 8 weeks of age. It was also observed that the rumen volume of milk-fed calves is largely unused.

Jacobson et al. (17) observed that when calves are fed a liquid diet the rumen and reticulum increase rather substantially even though the tissue weight per unit of body weight does not increase to any great extent for several months.

In vivo measurements have been made of the volume or capacity of the rumen in young calves. Flatt et al. (9) measured rumen capacity in calves 5, 9, 13, and 17 weeks of age, and Harrison and Warner (12) measured rumen capacity in calves 16, 28, and 48 weeks of age. These measurements revealed that the capacity of the rumen of calves receiving solid feed increased at a faster rate than body growth, while the rumen volumes of milk-fed calves increased at approximately the same rate as body growth.

Relation of Rumen Development to Absorption of Volatile Fatty Acids. Martin et al. (23) found that a diet for young calves which supplied acetic, propionic and butyric acids, in the form of salts, in the same proportions as they usually occur in a normally functioning rumen resulted in a higher concentration of volatile fatty acids in blood than either a whole milk or a purified diet. The concentration of volatile fatty acids in blood was greater for the purified diet than for the whole milk diet. The magnitude of these increases tended to become greater with the advancing age of the calves. They stated that volatile fatty acids, either produced in the rumen or ingested in the diet, may be absorbed and metabolized by ruminants as young as 3 to 6 weeks of age. Jacobson et al. (17) reported that when a concentration of acetic acid similar to that found in the normally functioning rumen was introduced into the emptied rumen of calves which were receiving whole milk, only 5 to 10 per cent was absorbed over a 3-hour period. The efficiency of absorption changed very little with age. However, when calves were allowed to consume hay and grain the rate of absorption increased from 10 to 15 per cent at one week of age to 80-90 per cent at 13 weeks of age.

Rumination

Swanson and Harris (34) stated that rumination is an important adjunct to normal rumen function. Furthermore, they stated that the newborn calf or calves confined solely to a milk diet do not ruminate. However, Marshall et al. (22) reported the young calf will soon eat a considerable amount of roughage and at a relatively early age begin the process of rumination. Only Swanson and Harris (34) and Waugh et al. (42) have made visual observations on the ruminating activity of young calves.

Early Rumination and Rumen-Reticulum Contents. Young calves have been observed by several workers (34, 35, 42) to begin ruminating as early as 5 to 7 days of age. Swanson and Harris (34) observed the rumination activity of 26 calves at two-week intervals from 1 to 15 weeks of age. The calves were receiving a coarse-chopped, alfalfa-grass mixed hay and an 18 per cent pelleted starter ration. The observations were made 4 times for 6 hours at a time and covered parts of two days making a 24-hour observation. The calves began to ruminate as early as 5 to 7 days of age and by the time they were 15 to 28 days of age all were ruminating except one.

Kesler et al. (20) found that rumen contents from calves 6 weeks of age showed signs of rumination. When Swanson and Harris (34) slaughtered calves 12 to 17 days of age the rumen contents from the ruminating calves had the characteristic sharp acid odor of mature cattle whereas non-ruminating calves did not. They also found the abomasum contents to be greater than rumen contents in the non-ruminating calves whereas they were more nearly equal in the ruminating calves. On the basis of the amount and appearance of rumen contents, these workers concluded that rumination accompanies or precedes the development of normal rumen fermentation and digestion.

Ruminating Activity. Swanson and Harris (34) and Waugh et al. (42) found that both the number and length of ruminating times increased up to 5 to 6 weeks of age after which time the change in these factors was gradual. Swanson and Harris (34) observed calves to spend less than one hour ruminating when 9 days of age with the variability among calves being large, whereas Waugh et al. (42) found that calves 7 days of age

spent slightly more than one hour ruminating. In the latter work, the calves were fed wilted Klkuyu forage and observed for a 24-hour period.

Swanson and Harris (34) found the total rumination time reached about 3 hours by 2 weeks of age and about 5 hours by 6 weeks of age. In contrast to this, Waugh et al. (42) found the total rumination time reached slightly over 6 hours at 2 weeks of age and nearly 11 hours by 6 weeks, after which it tended to remain fairly constant. Swanson and Harris (34) found the time spent ruminating by calves over 6 weeks of age approached similar values reported by Castle et al. (3) and Hancock (10) for lactating cows and heifers.

Correlation of Rumination and Feed Consumption. Hancock (10) found the time spent ruminating to be correlated with feed intake in first-calf heifers. A significant correlation was also found between rumination time and feed intake for young calves by Swanson and Harris (34). They noted that some calves which were 3 weeks of age and consuming an average of one pound of grain daily, spent up to 5 hours ruminating. After the calves begin to consume more grain, there was little increase in the time spent ruminating which indicates that development of normal rumen function is a usual precedent for the calf to be able to handle large amounts of dry feed properly. These workers also observed that diarrhea reduced rumination time, but at the same time only very slight reductions in daily feed consumption accompanied the diarrhea attacks.

Early Weaning

Several workers (5, 7, 30, 43, 45) have found that young dairy calves can be weaned at 28 days of age provided they are vigorous, in good health, and have begun to consume dry feed. These workers also have noted

that calves will obtain normal growth on concentrate rations which are made up entirely of plant materials with no animal protein included.

Preston et al. (28) fed a ration containing milk by-products and weaned calves successfully at 21 days of age. Noller et al. (27) also found that calves fed a starter ration containing 19 per cent crude protein and inoculated with fresh rumen contents may be weaned with satisfactorily results at 21 days of age. However, Yang et al. (45) found that 4 weeks of age was the earliest time at which calves could be weaned with consistent results.

Castle and Watson (4) compared a conventional system and an early-weaning system in which calves were weaned at 35 days of age. They found no difference between the two systems when judged on the basis of live-weight gain, health, and general appearance. They recommended the early-weaning system since it was the cheaper of the two systems.

EXPERIMENTAL PROCEDURE

Twenty-four male Holstein calves were used to evaluate the effectiveness of a mixture of fatty acid salts with respect to rumen mucosal development and to check the growth and well-being of early weaned calves fed a starter ration which contained a mixture of fatty acid salts. Sixteen of the 24 calves were used to determine whether or not a relationship existed between the composition of the starter ration and the onset of rumination in young dairy calves.

Management of Calves. The calves were removed from their dams when 1 to 2 days of age and placed in individual tie stalls with elevated metal screen floors. Colostrum was fed to the calves through 3 days of age, and the calves were started on experiment the fourth day after birth. The calves were fed whole milk twice daily at the rate of 10 per cent of body weight for 14 days and then the amount of milk was reduced to 8 per cent of the initial body weight for an additional 10 days. One-half gram of chlortetracycline, in the form of aurofac-D, was fed daily in the milk for the first week and then the amount was reduced to 50 mg. per day until the calves were weaned abruptly at 28 days of age.

The calves were grouped into 3 blocks of 8 calves each according to season of birth. The calves within each block were assigned at random to either an experimental or control ration. The experimental ration (Ration I) consisted of a basal ration plus a mixture of fatty acid salts. The control ration (Ration II) was made up of the same basal ration with

glucose added as a readily available source of energy (Table I). The mixture of fatty acid salts (Table II) and the glucose each made up 10 per cent of the respective ration in which it was included. On a molar basis, equal amounts of propionate and butyrate were used. The amounts of calcium, potassium, and sodium salts were calculated to give an equal amount of each of the salts in the mixture.

The respective ration to which each calf had been assigned was placed before it at 4 days of age. Each calf was encouraged to eat the ration twice daily by placing a small amount of the ration in his mouth until he had began to consume the ration. Daily feed consumption was recorded for each calf. Fresh water was kept before the calves at all times.

Two consecutive weights, one the evening of the third day and the other the morning of the fourth day after birth, were taken for each calf at the start of the experiment. The average of these weights were then used in determining the amount of milk the calves were to receive. The calves were weighed weekly throughout the experiment and on two consecutive days before being sacrificed at 39 days of age.

Activity of Calves. Observations were made on the ruminating activity of 16 calves during the duration of this study. Observations on the time spent ruminating, resting, standing, eating, and drinking were made during two 24-hour periods. The first observation was made when the calves were 11 days of age and the second observation was made at 25 days of age.

Slaughter of Calves. When the calves were sacrificed at 39 days of age the digestive tract, with the exception of the esophagus, was removed. Each compartment of the stomach was dissected free from its omenta and stripped of its larger blood vessels, lymph nodes, and fat. The compartments were then weighed before and after the removal of ingesta. The

TABLE I

Composition of Control and Experimental Rations

Ingredient	Control (%)	Experimental (%)
Cubed corn	20	20
Crimped oats	20	20
Wheat bran	6	6
Corn distillers solubles	5	5
Dried molasses	4	4
Soybean meal (41%)	12	12
Alfalfa meal crumbles	20	20
Dicalcium phosphate	1	1
Trace mineral salt	1	1
Antibiotic-vitamin-mix[a]	1	1
Glucose	10	--
Mixture of fatty acid salts	--	10

[a]Amounts/lb. of ration: Aureomycin, 25 mg.; Vitamin A, 2500 I.U.; Vitamin D_2, 312.5 I.U.; Vitamin B_{12}, 0.0075 mg.; Riboflavin, 5 mg.; Pantothenic acid, 10 mg.; Niacin, 22.5 mg.; Thiamine, 15 mg.; and d-biotin, 0.15 mg.

TABLE II

Composition of Mixture of Volatile Fatty Acid Salts

Fatty acid salt	Molecular weight (g.)	Total weight (%)	Amount/cwt. of ration (lb.)
Na propionate	96	10.5	1.05
K propionate·H_2O	130	14.2	1.42
Ca propionate·H_2O	204	22.3	2.23
Na butyrate	110	12.0	1.20
K butyrate·H_2O	144	15.7	1.57
Ca butyrate·H_2O	232	25.3	2.53

small and large intestines were also weighed both before and after the removal of ingesta for the purpose of determining the weight of ingesta contained therein. After the combined empty weight of the rumen-reticulum was obtained the rumen and reticulum were separated.

A 10 x 10 cm. section of the dorsal cranial sac of the rumen was taken and separated into its muscle and mucosal layers. Each layer was weighed and placed in a drying oven at 90°C for 48 hours. The layers were removed from the oven and allowed to come to equilibrium with the atmosphere before they were again weighed to obtain the dry weight. A 1 x 1 cm. section of the dorsal cranial sac was taken and preserved in chloroform for a histological study. The remainder of the rumen was separated into mucosal and muscle layers and each layer weighed before calculating the total percentage of muscle and mucosa.

Observance of Parakeratosis. The last 16 calves were observed for the incidence and severity of ruminal parakeratosis. Observations were made at the time of slaughter as to the extent of incrustation of the papillae. The 1 x 1 cm. sections from the dorsal cranial sac of the rumen were observed grossly for any abnormal condition, after which microscopic sections were prepared for a histological study. Photographs were taken of all of the 1 x 1 cm. sections, using a Rolloflex type camera. Enlarged photographs of seven sections were also made using a Graflex type camera.

Determination of Rumen Volatile Fatty Acids. Four additional Holstein calves were used to determine the pH and molar percentages of ruminal volatile fatty acids. The calves were managed the same as the previous 24 calves. The first sample was collected by stomach tube when the calves were 18 days of age and then at weekly intervals until 39 days of

age when the calves were sacrificed. One sample was collected just before the calves were slaughtered and another one when the rumen was removed and opened. The pH readings were taken immediately after the samples were drawn from the calves. The sample of rumen fluid was then placed in a bottle and frozen until the analysis for volatile fatty acids was made, using the method described by Keeney (19).

RESULTS AND DISCUSSION

Rumen Development

Body Weights and Feed Consumption. The calves receiving the control ration (Ration II) had higher weekly weight gains than those receiving the ration containing the volatile fatty acid salts, except during the second week of the experiment (Table III). The average 5-week weight

TABLE III

Average Weekly Feed Consumption and Weight Gains

Ration	wk 1	2	3	4	5	Total
	Feed consumption, lb.					
C	0.8	2.2	6.4	9.8	17.6	36.3
FA	0.3	1.1	3.1	6.8	13.5	24.8
	Weight gains, lb.					
C	5.2	3.4	7.2	4.5	7.0	27.3
FA	2.3	4.4	4.8	4.3	6.2	21.9

gain for the calves receiving Ration II was 27.3 lb. as compared to 21.9 lb. for the calves which received Ration I. However, there was a large amount of variation among the calves in both groups with respect to weight gains so that the difference between groups was not statistically significant ($P > 0.05$). Martin et al. (23) also found no significant difference in live weight gains of calves fed a ration containing fatty acid salts as compared to those fed a purified diet.

The differences in live weight gains within the two groups of calves in the present study were probably at least partly due to differences in feed consumption (Table IV). However, there was no significant difference

TABLE IV

Total Weight Gains and Feed Consumption for Each Calf Through 39 Days of Age

Control			Fatty Acid Salts		
Calf number	Weight gain (lb.)	Feed consumption (lb.)	Calf number	Weight gain (lb.)	Feed consumption (lb.)
273	25.0	24.8	271	9.0	16.5
275	33.0	33.1	272	30.0	28.0
276	39.0	48.5	274	7.0	11.1
278	37.0	56.7	277	41.0	45.3
279	29.0	25.3	280	29.0	27.2
281	14.0	20.8	283	28.0	30.6
282	24.0	39.0	284	19.0	21.6
286	12.0	19.8	285	17.0	18.2
287	17.0	20.7	288	7.0	13.1
289	47.0	57.8	290	10.0	22.0
292	34.0	67.8	291	36.0	43.2
293	14.0	11.0	294	20.0	22.1
Average	27.1	35.4		21.1	24.9

($P > 0.05$) between treatment groups with respect to the average amount of grain consumed, i.e., 35.4 vs. 24.9 lb. for Ration II and Ration I, respectively. The 12 calves which received the control ration were all consuming grain by the time they were 11 days of age, whereas two of the calves receiving the VFA ration had not consumed any grain at this age.

When the calves were slaughtered at 39 days of age, no significant differences were found between treatments with respect to live weights or ingesta-free weights (Appendix Table XVII). However, a significant difference was found between treatments for the weight of ingesta in favor of the calves that received the control ration.

Weight of Rumen, Reticulum, and Omasum-Abomasum. The average rumen weight for the calves receiving the control ration was 635 g. as compared to 543 g. for those receiving the VFA ration (Table V). The average

TABLE V

Average Weights of Rumen, Reticulum, and Omasum-Abomasum

		Total		Amount/lb. ingesta-free weight	
		Control	Fatty acid	Control	Fatty acid
Rumen					
Total	g.	635.5	543.1	6.3	5.5
Mucosa	g.	338.8	278.9	3.3	2.8
Muscle	g.	269.1	238.6	3.0	2.7
Mucosa	%	55.2	53.9	53.0	50.9
Reticulum	g.	140.2	133.1	1.4	1.4
Omasum-Abomasum	g.	381.6	409.4	3.8	4.3

weight of the reticulum was also greater for the animals receiving Ration II than for those on Ration I, being 140 and 133 g. for the two rations, respectively. There was a difference in the total weight of the mucosal and muscle tissue, also in favor of the calves receiving Ration II.

The average weight of the rumen per pound of ingesta-free weight was found to be greatest for the calves receiving Ration II, whereas no difference was found between the rations for the average weight of the reticulum per pound of ingesta-free weight (Table V). However, the calves receiving Ration I had a larger omasum-abomasum than those receiving Ration II. The average weights of the omasum-abomasum were 4.3 and 3.8 g. per pound of ingesta-free weight for Ration I and II, respectively.

The weight of the mucosal tissue per pound of ingesta-free weight was 3.3 g. for calves receiving Ration II as compared to 2.8 g. for those receiving Ration I. The weight of muscle tissue per pound of ingesta-free

weight was 3.0 g. for Ration II and 2.7 g. for Ration I. However, the differences between treatments with respect to the weight of the different parts of the stomach, expressed as grams per pound of ingesta-free weight, were not statistically significant ($P > 0.05$). Similarly, Sander et al. (31) found no significant difference between calves "fed" a glucose solution and those given solutions of fatty acid salts with respect to weight of rumen muscle per unit of body weight. However, they did find a significant difference between treatments with respect to mucosal tissue in favor of the calves which received either a solution of sodium butyrate or sodium propionate.

The percentage of total mucosal tissue was greater for the calves which received Ration II than for those fed Ration I (Table V). The average percentage of total mucosa obtained by feeding Ration II was 53.0 as compared to 50.9 when Ration I was fed. However, the difference between the two rations was not statistically significant ($P > 0.05$). Thus, the effect of adding VFA salts to a starter ration were not the same as the effects previously reported by Sander et al. (31) and Flatt et al. (8) when solutions of fatty acid salts were administered to young calves through a cannula-type rumen fistula.

Rating of Mucosal Development. There was a considerable amount of variation among the calves within each of the groups with respect to development of the rumen papillae (Figure 1). Six of the eight calves fed Ration II had at least some papillary development, as compared to 4 of the group receiving Ration I (Table X). The reason for the variation among calves in papillary development was not apparent and could not be explained satisfactorily on the basis of the amount of grain consumed during different intervals. In contrast to these results, Sander et al.

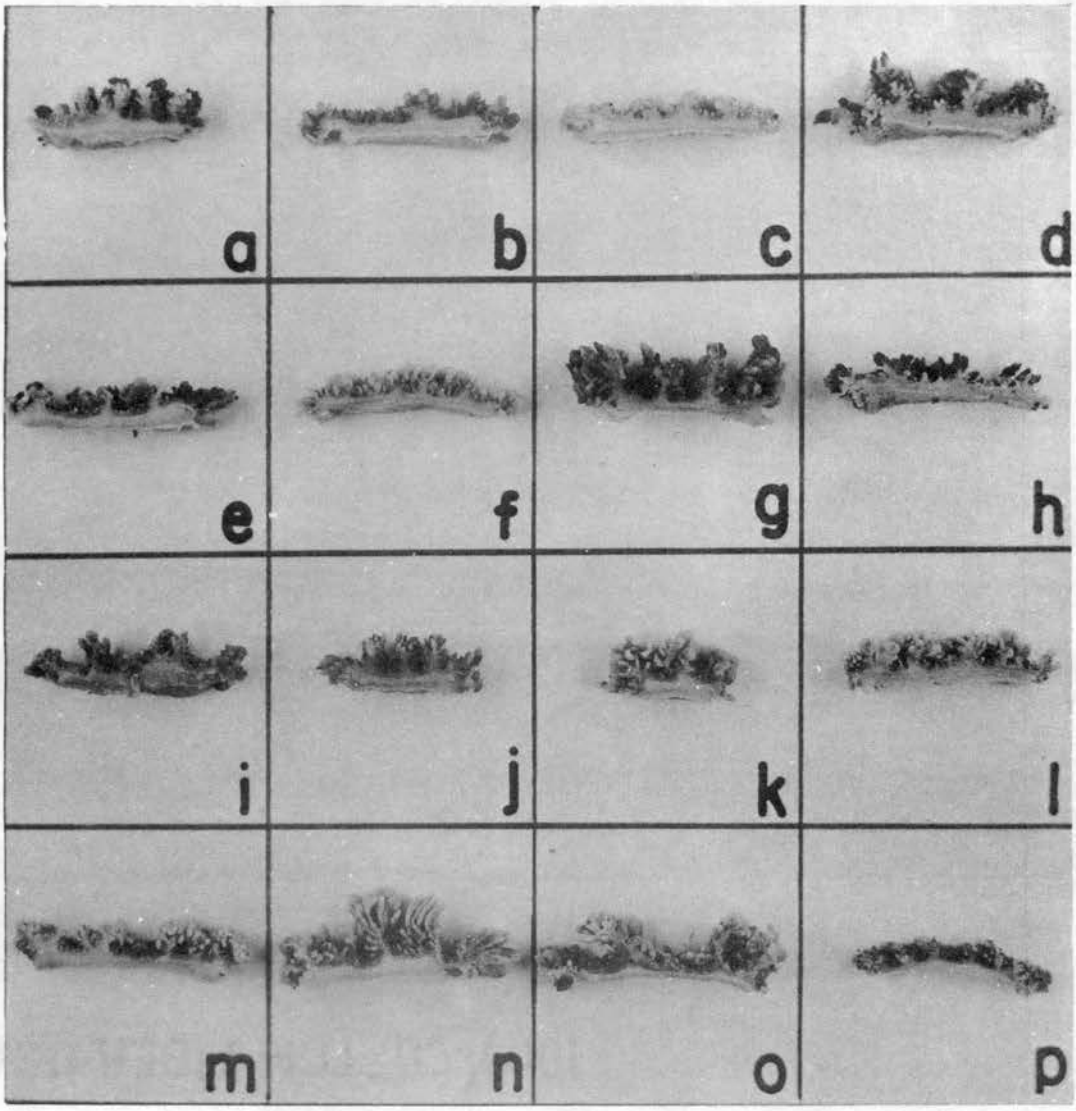

Figure 1. Side View of 10 x 10 cm. Sections of Rumen Tissue. (a-h received VFA ration and i-p received control ration)

(31) found that calves "fed" solutions of fatty acid salts via rumen fistulae had higher papillary scores than those "fed" a glucose solution.

Weight and Per Cent Mucosa of 10 x 10 cm. Sections on a Wet and Dried Basis. The percentage of mucosal tissue was greater for Ration II than for Ration I when compared on both a wet and dried basis (Table VI). The

TABLE VI

Average Weights of Mucosa and Muscle and Per Cent Mucosa for 10 x 10 cm. Section of Rumen Tissue

	Wet				Dry			
Ration	Total (g.)	Mucosa (g.)	Muscle (g.)	Mucosa (%)	Total (g.)	Mucosa (g.)	Muscle (g.)	Mucosa (%)
C	54.4	33.3	21.0	61.3	11.3	7.7	3.6	68.0
FA	51.0	28.4	21.9	55.4	10.9	6.6	4.3	60.6

calves receiving Ration II, which contained glucose, had an average of 61.3 per cent mucosa on a wet-basis and 68.0 per cent on a dried-basis, while those receiving the VFA ration had 55.4 and 60.6 per cent mucosa on a wet and dried basis, respectively. However, the differences noted between treatments were not statistically significant ($P > 0.05$) when considered on either a wet or dried basis.

Regression Analyses. Several regression analyses were made using feed consumption through the first 2 weeks, 28 days, or the entire experiment as an independent variable and certain measurements pertaining to the development of the rumen as dependent variables. Thus, an attempt was made to relate feed consumption to the weight of the total rumen, mucosa and muscle in grams per pound of ingesta-free weight, and percentage mucosa. Total feed consumption was not significantly related ($P > 0.05$)

to any of the dependent variables considered (Table VII). However, when feed consumed through 2 weeks of age was used as an independent variable all regression coefficients were significant ($P < 0.05$), except the one involving the weight of the rumen muscle. The highest degree of relationship was found between feed consumption the first 2 weeks and per cent mucosa for the 10 x 10 cm. section (Table VII and Figure 2). The amount of feed consumed through 28 days of age was significantly related ($P < 0.05$) to the weight of mucosa, weight of muscle, weight of rumen, and per cent mucosa for the 10 x 10 cm. section, but not to the per cent mucosa of the entire rumen.

TABLE VII

Regression Analyses Relating Feed Consumption to Rumen Development

Independent variable	Dependent variable	Regression coefficient
Feed consumed first 2 wk.	Total rumen	0.49*
Feed consumed first 2 wk.	Total muscle	0.08
Feed consumed first 2 wk.	Total mucosa	0.29*
Feed consumed first 2 wk.	% total mucosa (Wet)	1.43*
Feed consumed first 2 wk.	% mucosa 10 x 10 cm. section (Wet)	1.54*
Feed consumed to 28 days of age	Total rumen	0.15*
Feed consumed to 28 days of age	Total muscle	0.05*
Feed consumed to 28 days of age	Total mucosa	0.91*
Feed consumed to 28 days of age	% total mucosa (Wet)	0.30
Feed consumed to 28 days of age	% mucosa 10 x 10 mc. section (Wet)	0.40*
Total feed consumed	Total rumen	0.07
Total feed consumed	Total muscle	0.02
Total feed consumed	Total mucosa	0.04
Total feed consumed	% total mucosa (Wet)	0.15
Total feed consumed	% mucosa 10 x 10 cm. section (Wet)	0.20

*Statistically significant, ($P < 0.05$).

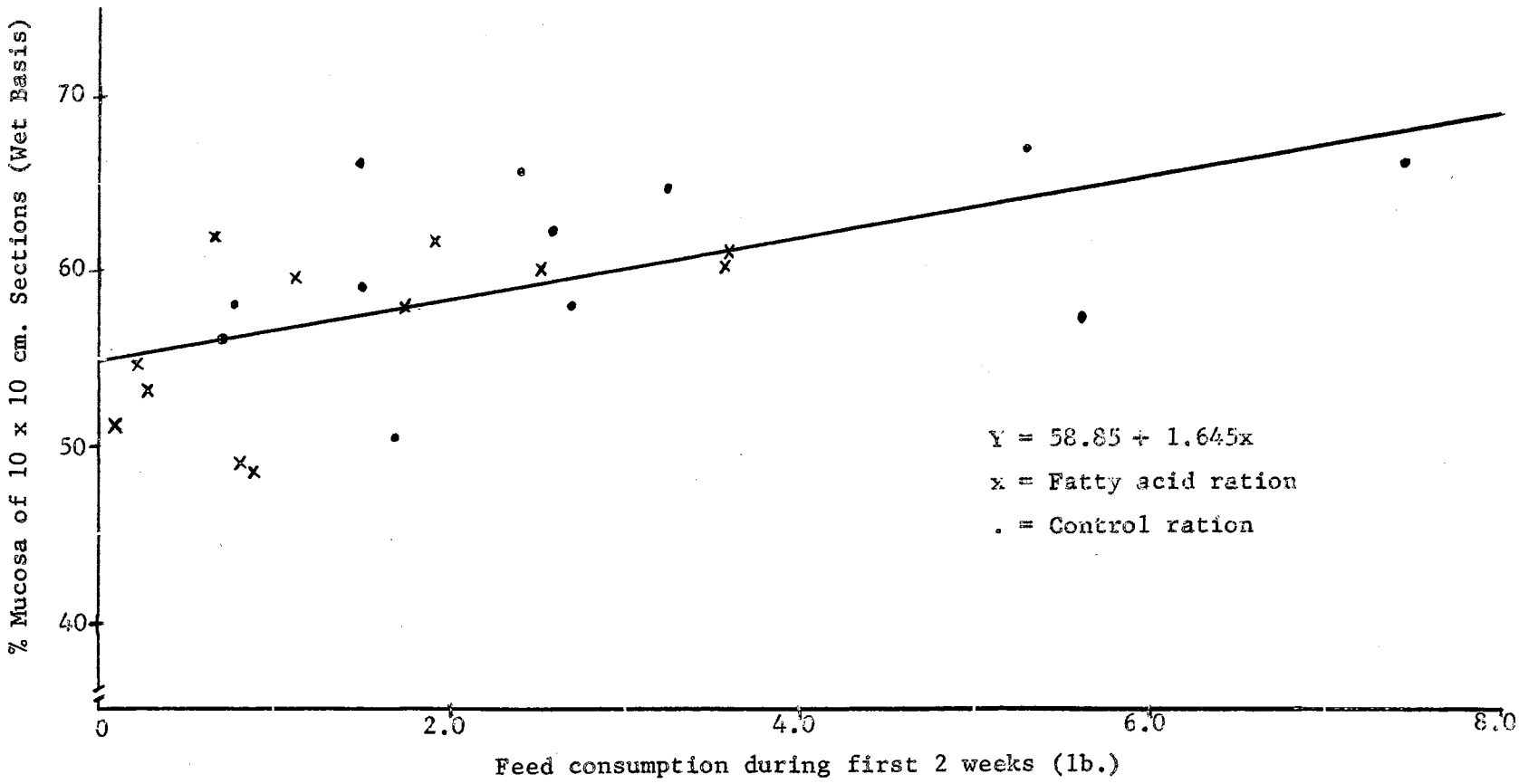

Figure 2. Regression of Per Cent Mucosa of 10 x 10 cm. Sections (Wet Basis) on Feed Consumption During First Two Weeks

From the above regression analyses it can be seen that consumption of a starter ration by calves at an early age is quite important. This is necessary in order to get early development of the rumen and continued good growth when calves are weaned at an early age.

Rumination

Ruminating Activity at Different Ages. Ruminating activity of the first 16 calves was observed twice during the duration of this experiment. The calves which received Ration II spent an average of 14 minutes per day ruminating when 11 days of age, as compared to 12 minutes for those receiving Ration I (Table VIII).

TABLE VIII

Observations on Time Spent by Calves in Eating, Drinking and Ruminating

Calf No.	Ration	At 11 days of age			At 25 days of age		
		Eating	Drinking	Ruminating	Eating	Drinking	Ruminating
		Min.			Min.		
271	FA	13	10	9	67	8	263
272	FA	28	12	3	44	16	179
274	FA	5	7	8	61	16	95
277	FA	25	9	3	49	11	176
280	FA	29	7	42	37	7	126
283	FA	11	12	17	79	7	117
284	FA	6	12	3	20	11	169
285	FA	16	7	14	3	44	109
Average		15.5	9.5	12.4	45.0	27.5	154.3
273	C	30	7	23	29	8	38
275	C	28	6	20	33	2	189
276	C	11	11	6	70	12	282
278	C	25	6	9	95	17	329
279	C	18	9	49	54	5	155
281	C	22	2	2	28	2	148
282	C	36	6	4	59	11	231
286	C	22	1	3	42	2	123
Average		24.0	6.0	14.5	51.3	7.4	186.9

At 25 days of age, the time spent ruminating was 187 and 154 minutes for the same two groups, respectively. Although the variation among calves in the time spent ruminating was large, all 16 calves were ruminating when 11 days of age. Tamate et al. (35) observed that calves receiving fatty acids began to ruminate when 7 days of age. Furthermore, Swanson and Harris (34) noted that calves began to ruminate when 5 to 7 days of age and spent less than one hour per day ruminating.

Although there was a difference in the amount of time spent ruminating at both observations in favor of the calves receiving the control ration, these differences were not statistically significant ($P > 0.05$). Moreover, the small differences observed were at least partly due to differences in the amount of feed consumed. The calves receiving Ration II had consumed an average of 0.86 lb. of grain when 11 days of age as compared to 0.25 lb. for the calves receiving Ration I (Table IX). At 25 days of age, the calves receiving Ration II had consumed an average of 9.42 lb. of grain, whereas those receiving Ration I had only consumed an average of 4.40 lb. of grain.

TABLE IX

Average Feed Consumption and Ruminating Time for Calves at 11 and 25 Days of Age

Ration	Age (da.)	Feed consumed (lb.)	Ruminating time (min.)
C	11	0.86[a]	14.0
FA	11	0.25[a]	12.0
C	25	9.42[b]	187.0
FA	25	4.40[b]	154.0

[a] 4 through 11 days of age.

[b] 4 through 25 days of age.

The calves receiving Ration I spent an average of 15 minutes eating and 10 minutes drinking per day when 11 days old, whereas the calves receiving Ration II spent an average of 24 minutes eating and 6 minutes drinking at this age (Table VIII). Even at this early age it can be seen that the calves spent more time consuming the ration which contained glucose than they did consuming the ration which contained the mixture of fatty acid salts, which would suggest that the ration containing glucose was more palatable.

When 25 days of age, the calves receiving Ration I spent an average of 45 minutes eating and 27 minutes drinking as compared to an average of 51 minutes eating and 7 minutes drinking for the calves receiving Ration II (Table VIII). Thus, the calves on Ration I spent nearly 4 times more time drinking than those on Ration II. Similarly, Martin et al. (24) observed that calves fed a ration containing fatty acid salts consumed nearly twice as much water as calves which were receiving a purified diet.

Correlation Between Rumination and Feed Consumption. Two correlation coefficients were computed to determine the degree of relationship between the amount of time spent ruminating and feed consumption. A non-significant ($P > 0.05$) coefficient of 0.21 was obtained between the amount of time spent ruminating at 11 days of age and the amount of feed consumed to that age. However, at 25 days of age a significant correlation coefficient ($P < 0.05$) of 0.53 was found between rumination time and feed consumption. Similarly, Swanson and Harris (34) obtained a highly significant correlation coefficient of 0.51 between rumination time and feed consumption of calves 6 to 16 weeks of age.

Rumen Parakeratosis

Observations of Rumen Parakeratosis. In the present study, observations were made after the calves were sacrificed at 39 days of age for the incidence of rumen parakeratosis. The 1 x 1 cm. section taken from the dorsal cranial sac of the rumen of each calf and also the entire surface of the rumen were considered in making the evaluations. Seven of the calves receiving Ration I either had parakeratosis or exhibited signs of developing it, as compared to only 3 of the 8 calves which received Ration II (Table X).

TABLE X

Occurrence and Severity of Rumen Parakeratosis

Calf No.	Ration	Parakeratosis	Severity[b]	Mucosal development[c]
279	C	No		++
281	C	No[a]		++
282	C	No		++
286	C	No		+
287	C	No		0
289	C	No		+++
292	C	No[a]		++
293	C	Yes	++	0
280	FA	Yes	++	+
283	FA	No[a]	+	+
284	FA	No[a]	+	0
285	FA	Yes	++	++
288	FA	Yes	++	0
290	FA	No	+	0
291	FA	Yes	++	++
294	FA	Yes	++	0

[a] Some parakeratosis, although not definite.

[b] ++ = most severe; + = slight.

[c] Arbitrary scale used in evaluation: +++ = extensive development; 0 = very little development.

The rumen of calf No. 289 was typical of the majority of the animals receiving the control ration in that it had well-developed, smooth papillae with no incrustation (Figure 3). In contrast, the papillae of calf No. 291, typical of the calves receiving the VFA ration, were well-developed but incrusted with dark keratinized material (Figure 4). A papillae, with the cap desquamated, is shown in Figure 5.

There was a large amount of variation in the degree of mucosal development; however, the calves which received the control ration had a more extensive development in the majority of cases (Table X and Figures 1 and 7). The calves receiving the VFA ration had the highest incidence of rumen parakeratosis and less extensive development of mucosal tissue than those receiving the control ration. In Figure 7, parakeratosis is evident in sections a, d, e, g, h and p.

Ruminal parakeratosis is a noncontagious disease which is characterized grossly by a hardening and enlargement of papillae and microscopically by the accumulation of excessive layers of keratinized, nucleated, squamous epithelial cells on the papillae (18, 36). Several workers (16, 18, 29, 36) have observed rumen parakeratosis when lambs were fed high-concentrate pelleted rations. Other workers (1, 6, 26) have noted rumen parakeratosis when steers were fed a similar type ration.

Although rumen parakeratosis has been observed by a number of workers (1, 6, 15, 16, 18, 25, 26, 36, 38, 39) under various conditions, its cause has not been determined. However, it is likely due to a change in the concentration or absorption of volatile fatty acids and/or the development of more acid conditions in the rumen. Rhodes and Woods (29) found greater butyric acid utilization by rumen epithelium from lambs fed high-concentrate rations, in either a mixed or pelleted form, than from

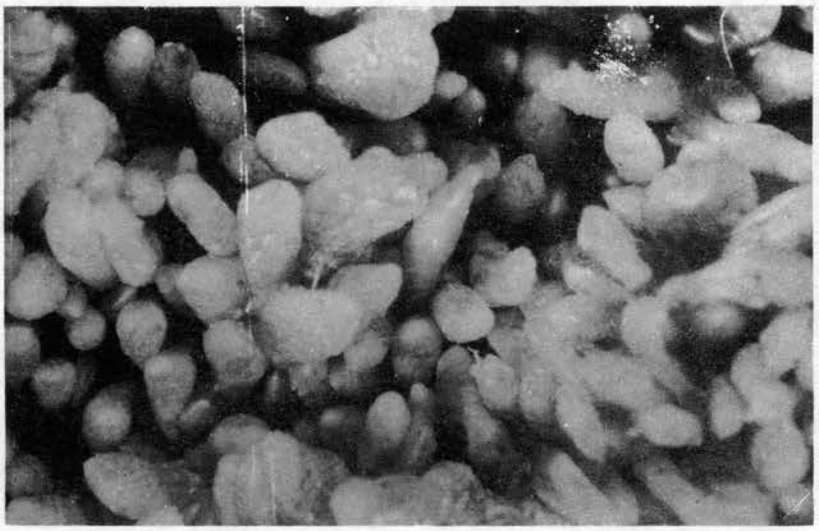

Figure 3. Well-Developed Papillae with no Incrustation. Calf No. 289

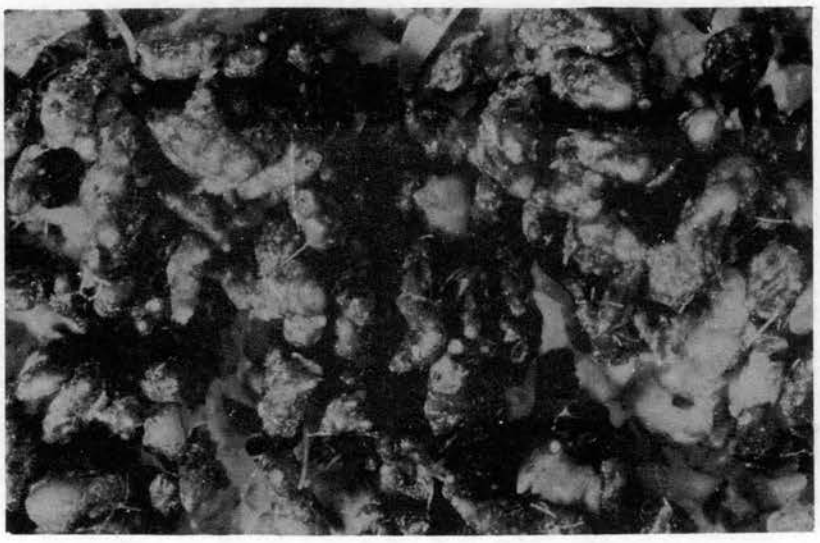

Figure 4. Well-Developed Papillae with Incrustation Indicating Parakeratosis. Calf No. 291

Figure 6. Section of Rumen Wall Showing the Muscle and Mucosal Tissue

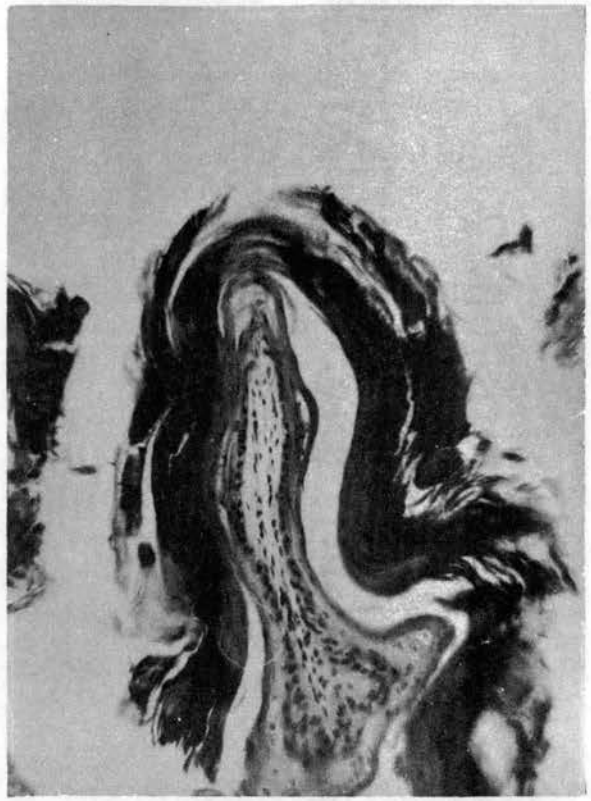

Figure 5. Papillae with Its Cap Desquamated.

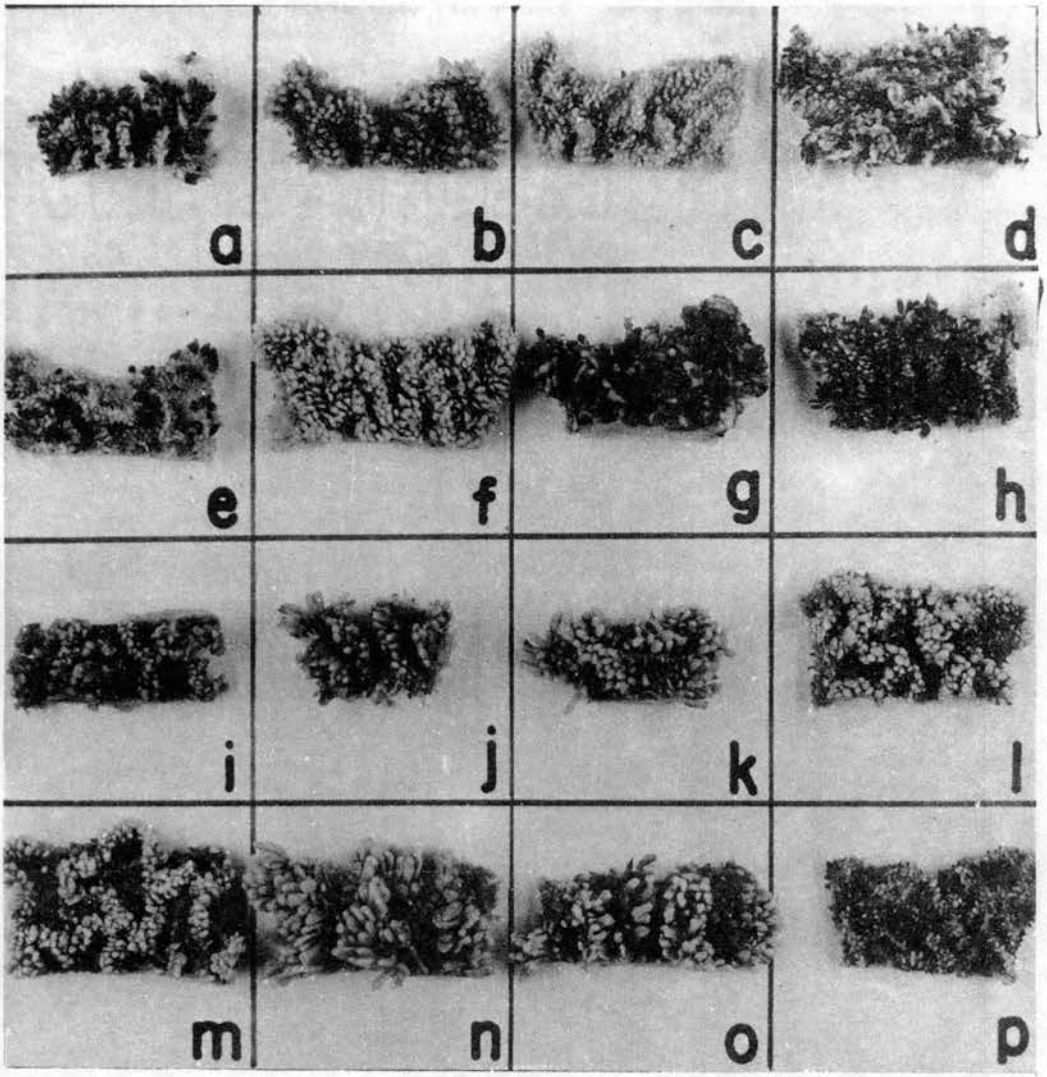

Figure 7. Dorsal View of 10 x 10 cm. Sections of Rumen Tissue from Last 16 Calves. (a-h received VFA ration and i-p received control ration)

lambs fed the same rations containing long hay. Vidacs and Ward (39) suggested that a low acetate to propionate ratio may be the cause of rumen parakeratosis and that destruction of rumen papillae may be related to alterations in volatile fatty acid absorption. Several workers (6, 15, 29) have obtained lower rumen pH values in animals receiving pelleted feeds as compared to long hay. Vidacs et al. (38) suggested that development of rumen parakeratosis is due to the presence of a heat sensitive or protein bound factor in the rumen fluid.

The fact that the calves receiving the VFA ration in the present study had the greatest incidence of rumen parakeratosis would tend to support the suggestion, that the concentration or utilization of volatile fatty acids in the rumen may be related to the occurrence of parakeratosis.

Rumen Volatile Fatty Acid Studies. There was no incidence of parakeratosis in the 4 calves used in the study of rumen pH and VFA. This may have been due to a smaller amount of grain consumption by these calves during the first two weeks on experiment as compared to those previously observed (Table XI). The calves on Ration I consumed an average of 1.43 lb. of grain during this period in the previous study as compared to 0.32 lb. in this study. The calves receiving Ration II consumed an average of 2.95 lb. of grain during the first 2 weeks in the previous study and only 0.60 lb. in this study. The smaller amount of feed consumed by the calves may have resulted in a lower concentration of volatile fatty acids in the rumen. This would account for the lack of any occurrence of parakeratosis if the concentration or utilization of volatile fatty acids within the rumen is responsible for the development of this condition.

There was not a great amount of difference between the treatments in terms of pH values of the rumen fluid (Table XII). However, the calves

TABLE XI

Feed Consumed by Calves Used for Rumen Volatile Fatty Acid Studies

Calf No.	Ration	wk. 1	2	3	4	5	Total
65	C	1.12	0.68	4.63	7.31	17.38	31.12
48	C	0.69	0.52	5.52	11.30	11.30	29.33
	Average	0.90	0.60	5.07	9.30	17.09	30.22
9	FA	0.33	0.35	2.22	9.26	17.34	29.50
50	FA	0.70	0.29	0.88	4.64	9.00	15.51
	Average	0.51	0.32	1.55	6.95	13.17	22.51

TABLE XII

pH of Rumen Samples from Calves Receiving Different Rations

Calf No.	Ration	wk. 2	3	4	5	5[a]
65	C	6.0	4.9	5.5	5.8	6.0
48	C	9.4	5.8	5.7	5.3	5.5
9	FA	8.5	6.7	5.7	5.8	5.8
50	FA	6.2	6.2	6.4	6.6	-

[a]pH value of sample taken at slaughter.

receiving the ration which contained the fatty acid salts tended to have the highest pH values. The pH at 3 weeks of age was higher for the calves receiving the VFA ration than for those receiving the control ration. This may be explained by the difference in feed consumption since the calves receiving the VFA ration consumed an average of only 1.55 lb. of grain during the third week as compared to an average of 5.07 lb. for those receiving the control ration. Thus, the calves receiving Ration II probably had a less active rumen fermentation than those receiving Ration I which would tend to account for the higher pH values. The relatively

consistent pH values from one week to the next for calf No. 50 was most likely due to the small amount of feed being consumed, with a consequent lack of active rumen fermentation.

The total concentration of rumen fatty acids tended to increase from the first through the fourth week on experiment (Table XIII). Similarly, Martin et al. (23) observed that the concentration of blood volatile fatty acids tended to increase with advancing age in young calves. In the present study, Ration II resulted in a higher molar percentage of butyric acid than Ration I. However, Ration I resulted in higher molar percentages of acetic and propionic acids than Ration II.

The results obtained from the four calves used in this study added nothing to our understanding of rumen parakeratosis since none was observed.

TABLE XIII

Total Concentration and Molar Percentage of Butyric, Propionic and Acetic Acids in Rumen Fluid

Calf No.	Ration	Acid	Week on experiment 2	3	4	5	5[a]	2	3	4	5	5[a]
			meg./100 ml.					Mole %				
65	C	C_4	1.11	3.50	3.49	2.34	3.20	20.2	36.5	33.6	17.4	18.8
		C_3	1.39	2.49	3.31	5.35	6.71	16.2	26.0	31.4	39.8	39.5
		C_2	3.49	3.59	3.59	5.76	7.08	63.6	37.5	34.5	42.8	41.7
	Total		6.99	9.48	10.39	13.45	16.99					
48	C	C_4	0.03	0.71	1.96	4.01	3.62	1.1	13.0	20.1	27.5	24.0
		C_3	0.52	1.59	3.25	3.45	3.92	23.7	29.3	33.4	23.7	26.0
		C_2	1.80	3.14	4.54	7.10	7.55	75.2	57.7	46.5	48.8	50.0
	Total		2.35	5.44	9.75	14.56	15.09					
9	FA	C_4	0.06	1.41	1.74	3.32	2.21	3.4	18.5	11.4	18.1	13.7
		C_3	0.28	2.21	6.41	7.84	7.13	16.3	29.0	42.0	42.7	44.0
		C_2	1.41	4.00	7.13	7.20	6.87	80.3	52.5	46.6	39.2	42.3
	Total		1.75	7.62	15.28	18.36	16.21					
50	FA	C_4	0.00	0.87	1.09	0.84	-	0.0	10.4	13.9	8.3	-
		C_3	0.02	3.02	3.17	3.63	-	12.0	36.0	40.6	35.7	-
		C_2	0.11	4.50	3.55	5.71	-	88.0	53.6	45.5	56.0	-
	Total		0.13	8.39	7.81	10.18	-					

[a]Taken at time of slaughter.

SUMMARY AND CONCLUSIONS

Twenty-four male Holstein calves were used to evaluate the effectiveness of a starter ration containing a mixture of fatty acid salts with respect to rumen mucosal development, growth, and well-being of early-weaned dairy calves. The calves were grouped into 3 blocks of 8 calves each according to their season of birth. The calves within each block were then assigned at random to either a ration containing glucose or to one containing a mixture of fatty acid salts.

No significant differences were obtained between the two treatments in terms of mucosal or muscular development of the rumen on either a wet or dried basis, feed consumption, or total weight gains ($P > 0.05$). However, a significant regression coefficient ($P < 0.05$) was found between feed consumption through 2 weeks of age and the weight or percentage of mucosa. This indicates that early grain consumption is essential for early rumen development regardless of the composition of the starter ration. Although these results are not in complete agreement with those of other workers (2, 8, 9, 11, 23, 31, 37, 40), they do not contradict the suggestion that rumen development may be stimulated by rumen volatile fatty acids.

Sixteen of the 24 calves were used to determine whether or not a relationship existed between the composition of the starter ration and the onset of rumination in young dairy calves. The ruminating activity, which included the time spent eating, drinking, and ruminating, was observed for two 24 hour periods. No significant differences ($P > 0.05$)

were noted between treatments for the amount of time spent ruminating at 11 or 25 days of age. However, a significant correlation coefficient ($P < 0.05$) was obtained between the amount of feed consumed through 25 days of age and the amount of time spent ruminating at this age for all 16 calves. Thus, it may be concluded that the composition of the starter ration did not have any effect upon the onset of rumination since all 16 calves were ruminating at 11 days of age.

The last 16 calves were observed for the incidence of rumen parakeratosis and 5 of the calves receiving the ration containing fatty acid salts developed this condition, whereas only one of the calves receiving the control ration developed it. It was thought that the concentration of volatile fatty acids in the rumen was responsible for this condition. Rumen samples were obtained from 4 additional calves, 2 on each ration, and analyzed for volatile fatty acids and pH readings taken. However, when the 4 calves were sacrificed at 39 days of age none had developed parakeratosis.

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A P P E N D I X

TABLE XIV

Weekly Feed Consumption and Weight Gains

Calf Number	Ration	Feed consumed (lb) wk 1	2	3	4	5	Weight gains (lb) wk 1	2	3	4	5
271	FA	.00	.27	2.94	3.21	10.03	-2.00	4.00	2.00	4.00	1.00
272	FA	.00	1.92	3.58	7.45	15.06	6.00	3.00	12.00	4.00	5.00
274	FA	.00	.10	.40	3.17	7.41	1.00	2.00	3.00	-1.00	2.00
277	FA	.34	3.25	6.77	12.56	21.57	6.00	5.00	12.00	5.00	13.00
280	FA	.97	1.56	3.11	9.26	11.76	4.00	6.00	2.00	7.00	10.00
283	FA	.12	.53	2.85	10.22	16.92	1.00	6.00	2.00	8.00	11.00
284	FA	.16	.64	2.25	4.01	14.67	0.00	7.00	3.00	2.00	7.00
285	FA	.46	.66	2.41	4.55	10.11	4.00	5.00	3.00	1.00	4.00
288	FA	.18	.69	2.57	4.55	5.07	0.00	3.00	4.00	-1.00	1.00
290	FA	.08	.14	1.12	5.26	15.44	0.00	2.00	4.00	7.00	-3.00
291	FA	1.42	2.14	7.73	12.46	19.44	4.00	8.00	4.00	10.00	10.00
294	FA	.24	1.50	2.74	5.04	11.58	4.00	2.00	6.00	5.00	3.00
Average		0.33	1.12	3.21	6.81	13.26	2.33	4.42	4.75	4.25	6.17
273	C	1.12	2.11	4.10	4.13	13.35	11.00	2.00	9.00	-3.00	6.00
275	C	.93	1.75	4.17	9.96	16.32	5.00	8.00	5.00	8.00	7.00
276	C	.11	2.45	10.65	15.19	20.10	3.00	6.00	13.00	6.00	11.00
278	C	2.68	2.95	11.93	19.05	20.13	5.00	5.00	14.00	5.00	8.00
279	C	.46	1.21	4.10	6.81	12.67	8.00	2.00	3.00	6.00	12.00
281	C	.67	.87	3.30	5.09	23.53	6.00	0.00	7.00	0.00	1.00
282	C	.30	2.12	6.82	10.15	19.59	4.00	0.00	9.00	4.00	7.00
286	C	.42	1.09	9.08	5.49	10.58	2.00	5.00	2.00	1.00	2.00
287	C	.35	.42	2.05	5.97	11.95	10.00	-2.00	1.00	3.00	5.00
289	C	2.05	3.26	9.44	15.36	27.70	6.00	5.00	14.00	10.00	12.00
292	C	.08	7.37	10.69	18.17	28.47	-4.00	5.00	10.00	9.00	14.00
293	C	.26	.42	.64	2.42	7.22	6.00	5.00	-1.00	5.00	-1.00
Average		0.79	2.17	6.41	9.82	17.63	5.17	3.42	7.17	4.50	7.00

TABLE XV

Analysis of Variance of Total Feed Consumption

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	634	634.0	2.672
Blocks	2	275	137.5	
T x B	2	221	110.0	
Error	18	5,401	237.3	
Total	23			

TABLE XVI

Analysis of Variance of Total Weight Gains

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	216	216.0	1.574
Blocks	2	161	80.5	
T x B	2	275	137.5	
Error	18	2,470	137.2	
Total	23	3,122		

TABLE XVII

Live Weight, Weight of Ingesta, and Ingesta-Free Weight at Slaughter

Calf Number	Ration	Live weight[a]	Weight of ingesta[b]	Ingesta-free weight[a]
		lb.		
271	FA	113.00	11.90	101.10
272	FA	122.00	17.60	104.40
274	FA	85.00	11.60	73.40
277	FA	130.00	13.50	116.50
280	FA	109.00	17.40	91.60
283	FA	116.00	12.70	103.30
284	FA	100.00	13.90	86.10
285	FA	106.00	15.20	90.80
288	FA	89.00	8.40	80.60
290	FA	111.50	10.30	101.20
291	FA	132.00	15.90	116.10
294	FA	104.00	7.60	96.40
Average		109.79	13.00	96.79
273	C	112.00	20.40	91.60
275	C	116.50	17.80	98.70
276	C	121.50	18.70	102.80
278	C	138.00	23.00	115.00
279	C	108.00	19.00	89.00
281	C	104.00	9.60	94.40
282	C	125.50	15.40	110.10
286	C	91.50	10.50	81.00
287	C	98.50	12.70	85.80
289	C	137.50	20.30	117.20
292	C	130.50	16.60	113.90
293	C	99.50	10.10	89.40
Average		115.25	16.17	99.08

[a]Differences between groups not statistically significant ($P > 0.05$).

[b]Differences between groups statistically significant ($P < 0.05$).

TABLE XVIII

Analysis of Variance of Live Weight at Slaughter

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	62	62	0.106
Blocks	2	426	213	
T x B	2	120	65	
Error	18	10,573	587	
Total	23	11,191		

TABLE XIX

Analysis of Variance of Weight of Ingesta at Slaughter

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	61	61.0	5.213
Blocks	2	68	34.0	
T x B	2	60	30.0	
Error	18	211	11.7	
Total	23	400		

TABLE XX

Analysis of Variance of Ingesta-Free Weight at Slaughter

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	31	31.0	0.167
Blocks	2	259	129.0	
T x B	2	9	4.5	
Error	18	3,331	185.1	
Total	23	3,630		

TABLE XXI

Total Weight of Rumen, Reticulum, Omasum-Abomasum, Mucosa, Muscle, and Per Cent Mucosa on Ingesta-Free Basis

Calf Number	Ration	Rumen	Reticulum	Omasum-Abomasum	Mucosa	Muscle	Mucosa
		g.					%
271	FA	615	138	360	268	294	47.69
272	FA	684	157	429	362	298	54.49
274	FA	349	113	307	163	176	48.08
277	FA	719	176	535	400	281	58.74
280	FA	507	143	402	261	227	53.48
283	FA	604	142	440	326	252	56.40
284	FA	355	97	409	166	171	49.26
285	FA	632	138	387	341	252	57.50
288	FA	317	95	265	126	205	38.07
290	FA	429	123	459	214	197	52.07
291	FA	850	158	526	477	328	59.25
294	FA	456	117	394	243	182	57.18
Average		543.08	133.08	409.42	278.92	238.58	53.90
273	C	711	150	338	388	308	55.75
275	C	675	121	404	357	280	56.04
276	C	800	185	378	371	400	48.12
278	C	770	137	490	344	364	48.59
279	C	545	143	293	289	245	54.12
281	C	465	130	337	262	181	59.14
282	C	645	134	495	379	246	60.64
286	C	334	88	284	184	131	58.41
287	C	554	133	334	252	277	47.64
289	C	934	175	441	553	361	60.50
292	C	913	199	540	540	310	63.53
293	C	280	87	245	135	126	51.72
Average		635.50	140.17	381.58	337.83	269.08	55.66

TABLE XXII

Weight in Grams Per Pound of Ingesta-Free Weight at Slaughter

Calf Number	Ration	Rumen	Reticulum	Omasum-Abomasum	Mucosa	Muscle
		g.				
271	FA	6.08	1.37	3.56	2.65	2.91
272	FA	6.55	1.50	4.11	3.47	2.85
274	FA	4.75	1.54	4.18	2.22	2.39
277	FA	6.17	1.51	4.59	3.43	2.41
280	FA	5.53	1.56	4.39	2.85	2.47
283	FA	5.85	1.37	4.26	3.16	2.44
284	FA	4.12	1.13	4.75	1.93	1.98
285	FA	6.96	1.52	4.26	3.76	2.77
288	FA	3.93	1.18	3.29	1.56	2.54
290	FA	4.24	1.22	5.52	2.11	1.94
291	FA	7.32	1.36	4.53	4.11	2.82
294	FA	4.73	1.21	4.09	2.52	1.88
Average		5.52	1.37	4.29	2.81	2.45
273	C	7.62	1.64	3.68	4.24	3.36
275	C	6.84	1.23	4.09	3.62	2.88
276	C	7.78	1.80	3.68	3.61	3.98
278	C	6.70	1.19	4.26	2.99	3.16
279	C	6.12	1.61	3.29	3.25	2.75
281	C	4.93	1.38	3.57	2.78	1.91
282	C	5.86	1.22	4.50	3.44	2.23
286	C	4.12	1.09	3.51	2.27	1.62
287	C	6.46	1.55	3.89	2.94	3.22
289	C	7.97	1.49	3.76	4.72	3.08
292	C	8.02	1.75	4.74	4.74	2.71
293	C	3.13	.97	2.74	1.51	1.41
Average		6.30	1.41	3.81	3.34	2.68

TABLE XXIII

Analysis of Variance of Omasum-Abomasum Expressed in Grams Per Pound of Ingesta-Free Weight

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	1.41	1.41	3.92
Blocks	2	0.01	0.01	
T x B	2	0.30	0.15	
Error	18	6.42	0.36	
Total	23	8.14		

TABLE XXIV

Analysis of Variance of Total Mucosa Expressed in Grams Per Pound of Ingesta-Free Weight

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	2.00	2.00	2.325
Blocks	2	1.00	0.50	
T x B	2	0.48	0.24	
Error	18	15.52	0.86	
Total	23	19.00		

TABLE XXV

Analysis of Variance of Total Muscle Expressed in Grams Per Pound of Ingesta-Free Weight

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	0.35	0.35	1.400
Blocks	2	2.26	1.11	
T x B	2	1.00	0.50	
Error	18	4.58	0.25	
Total	23	8.19		

TABLE XXVI

Analysis of Variance of Total Rumen Expressed in Grams Per Pound of Ingesta-Free Weight

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	3	3.00	1.530
Blocks	2	5	2.50	
T x B	2	5	2.50	
Error	18	32	1.77	
Total	23	45		

TABLE XXVII

Analysis of Variance of Reticulum Expressed in Grams Per Pound of Ingesta-Free Weight

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	0.01	.010	0.204
Blocks	2	0.08	.040	
T x B	2	0.08	.040	
Error	18	0.89	.049	
Total	23	1.08		

TABLE XXVIII

Weight of 10 x 10 cm. Section in Grams

Calf Number	Ration	Wet				Dry			
		Mucosa	Muscle	Total	Mucosa	Mucosa	Muscle	Total	Mucosa
		g.			%	g.			%
271	FA	25.00	22.00	47.00	53.20	5.00	3.00	8.00	62.50
272	FA	33.80	19.70	53.50	63.18	8.70	3.00	11.70	74.36
274	FA	24.00	23.00	47.00	51.06	5.20	7.50	12.70	40.94
277	FA	38.00	24.00	62.00	61.29	9.00	3.70	12.70	70.87
280	FA	28.70	19.00	47.70	60.17	7.50	3.00	10.50	71.73
283	FA	37.00	22.00	59.00	62.71	10.00	5.00	15.00	66.67
284	FA	23.50	24.50	48.00	48.96	4.80	3.90	8.70	55.17
285	FA	34.00	23.00	57.00	59.65	8.00	4.00	12.00	66.67
288	FA	23.20	24.50	47.70	48.64	7.00	5.00	12.00	58.33
290	FA	20.70	17.10	37.80	54.76	4.30	1.80	6.10	70.49
291	FA	33.91	22.95	56.86	59.64	8.10	3.47	11.57	70.01
294	FA	28.40	20.42	48.82	58.17	7.03	2.26	9.29	75.69
	Average	28.25	21.85	51.03	55.40	6.58	4.28	10.86	60.59
273	C	35.00	19.00	54.00	64.81	7.00	4.00	11.00	63.64
275	C	29.00	21.00	50.00	58.00	6.00	4.00	10.00	60.00
276	C	33.00	20.00	53.00	62.27	7.00	4.00	11.00	63.64
278	C	27.00	20.60	47.60	56.72	6.00	4.00	10.00	60.00
279	C	28.90	28.50	57.40	50.35	8.20	3.10	11.30	72.57
281	C	32.00	16.00	48.00	66.67	8.00	4.00	12.00	66.67
282	C	46.00	24.00	70.00	65.71	11.00	4.00	15.00	73.33
286	C	23.00	16.00	39.00	58.97	5.00	2.00	7.00	71.43
287	C	34.00	24.60	58.60	58.02	8.00	4.30	12.30	65.04
289	C	39.40	19.40	58.80	67.01	8.90	3.20	12.10	73.55
292	C	50.55	25.62	76.17	66.36	12.81	4.29	17.10	74.91
293	C	22.20	17.34	39.54	56.15	5.58	2.73	8.31	67.15
	Average	33.34	21.01	54.34	61.35	7.71	3.64	11.34	67.99

TABLE XXIX

Analysis of Variance of Per Cent Mucosa from 10 x 10 cm. Section of Rumen Tissue (Wet Basis)

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	103	103.0	3.111
Blocks	2	1	0.5	
T x B	2	18	9.0	
Error	18	596	33.1	
Total	23	718		

TABLE XXX

Analysis of Variance of Per Cent Mucosa from 10 x 10 cm. Section of Rumen Tissue (Dry Basis)

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	35	35.0	0.578
Blocks	2	248	124.0	
T x B	2	42	21.0	
Error	18	1,089	60.5	
Total	23	1,414		

TABLE XXXI

Analysis of Variance of Ruminating Time of Calves at 11 Days of Age

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	18	18.0	0.084
Blocks	1	176	176.0	
T x B	1	175	175.0	
Error	12	2,639	219.9	
Total	15	3,008		

TABLE XXXII

Analysis of Variance of Ruminating Time of Calves at 25 Days of Age

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Treatment	1	4,258	4,258.0	0.708
Blocks	1	8,696	8,696.0	
T x B	1	7	7.0	
Error	12	72,141	6,011.7	
Total	15	85,102		

VITA

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