COMPARISON OF PELLETED VERSUS LIQUID MILK REPLACERS FOR DAIRY CALVES

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The first few weeks of a calf's life constitute a critical period from the standpoint of nutritional requirements. The rumen of the calf is relatively undeveloped and essentially nonfunctional at birth; therefore, considerable development must take place with regard to establishment of the rumen microorganisms, increase in capacity, and growth of mucosal tissue necessary for absorption of the products of rumen fermentation. During the first few weeks of life, the calf is dependent upon a supply of feed nutrients that can be utilized without prior fermentation in the rumen. The range of ingredients that can be efficiently utilized by the nonruminating calf is rather limited due to the particular pattern of digestive enzymes available. Thus, the problem is one of providing the necessary nutrients during this relatively short, yet critical period in the most economical manner possible, with due regard for health, vigor, and growth of the calves.

The realization that rumen development does occur in calves at an early age without the aid of large amounts of liquid feeds has led to various methods of limited milk feeding on an early weaning basis. The high cost of raising calves on whole milk has also contributed to the wide-spread use of early weaning systems and to the use of inexpensive milk replacers in the diets of dairy calves as early as three days of age. Today, it is recognized that relatively large amounts of labor are required to feed calves milk or milk replacer via nipple pail. These factors have all contributed to the current interests in early weaning and the possibilities for feeding a milk replacer in pelleted form. Limited work by Rosser (65) has demonstrated that the idea of weaning calves to a dry pelleted replacer at an early age has merit in that calves can be raised in this manner. However, several aspects of the problem need further investigation before definite conclusions are reached concerning the feasibility of using this product in the field.

The research reported here represents a further attempt to obtain additional information concerning the feasibility of feeding a pelleted milk replacer to young dairy calves. The specific objectives of the present study were to (a) obtain information regarding the growth and feed consumption of young dairy calves fed a pelleted milk replacer as compared to calves fed a liquid milk replacer; (b) determine the relationship of the form of replacer to general thriftiness of calves and the incidence of certain infectious diseases, such as diarrhea and pneumonia; and (c) obtain information on certain rumen physiological functions incident to consumption of a pelleted replacer.

CHAPTER II

LITERATURE REVIEW

This review is limited to the major factors pertaining to nutrient utilization and rumen development of dairy calves during the first two months of life. This period was chosen because it covered the scope of the experiment conducted by the author and the development of rumen function. However, where information is limited on very young calves or milk replacers, reference will be made to similar data on older calves or starter rations.

Digestive Enzymes

Otterby et al. (58, 59) indicated that pregastric esterase has a major role in the digestion of milk fat in the abomasum of the calf. The level of free fatty acids in the abomasum was high only when milk passed through the oral cavity, the site of pregastric esterase secretion. They concluded that gastric lipase, if present at all, contributed little to abomasal hydrolysis of fat. Young et al. (80) reported that pregastric esterase secretion was not affected by the diet or age of calves.

Huber et al. (31) did not mention gastric lipase activity. They found that gastric protease levels were rather high at one day of age, reached a peak at eight days, and gradually decreased thereafter. Pancreatic amylase, lipase, and protease activities were lowest at one day of age, increased approximately three-fold the first week, and changed little with increase in age of calf. Intestinal lactase activity was highest at one day of age and decreased thereafter. Intestinal maltase levels were low, as compared to lactase, and increased little with age. Dollar and Porter (18) reported similar high lactase activity in very young calves and a decrease in activity with age. In contrast, amylase and maltase activities were low in young calves, but increased with age. No intestinal sucrase was detected (18,31). Huber et al. (31) suggested that the diet apparently exerted no major effect on the digestive enzyme levels. However, in a later study (35), they found that intestinal lactase concentrations were significantly increased as the lactose content of the diet increased.

Utilization of Milk Substitutes

In general, the ability of the calf to utilize specific carbohydrates was highly associated with the level of enzyme activity (18, 31). Responses in the levels of blood reducing sugar to ingestion of a given carbohydrate have been used as measures of carbohydrate utilization by the young calf. In these studies workers have consistently found good utilization of glucose and lactose; poor to fair utilization of maltose, improving with age; and poor utilization of sucrose and starch (18, 23, 24, 32, 33, 50, 56, 75). Digestion studies have shown much higher apparent utilization of starch and sucrose than was indicated by the blood sugar response to these carbohydrates (33, 50, 56). The disappearance of sucrose and starch was apparently due to the action of microorganisms in the posterior portion of the intestinal tract (18, 33, 50). The more readily digestible carbohydrates have been used in milk replacers at various levels between 3.5 and 60 per cent with varied success (23, 24, 46, 54). Flipse et al. (24) observed that calves fed a synthetic milk replacer containing 60 per cent glucose as the sole source of carbohydrate had very soft to semiliquid feces and approximately 0.14 kg daily gain from 2 to 33 days of age. When 10, 30, or 45 per cent of the glucose was replaced with corn syrup, the severity of the diarrhea increased. Whereas, calves maintained a normal fecal consistency and had an average daily gain of 0.27 kg when lactose was substituted for 5, 10, or 30 per cent of the glucose in the basal milk replacer. Lassiter et al. (44) fed low-fat milk replacers containing approximately 16, 29, 39, or 43 per cent cerelose to young dairy calves and reported adequate growth rates and a low incidence of diarrhea. Young calves fed milk replacers containing high levels of starch showed poor growth and a high incidence of digestive disorders (23, 30). Noller et al. (54, 55) reported that all-vegetable milk replacers containing 47 to 57 per cent ground corn produced inadequate weight gains and were poorly utilized by young dairy calves.

The utilization of various fats by young dairy calves has been reviewed by several researchers (4, 31, 37, 78). Barker et al. (4) reported that reconstituted nonfat milk containing freshly processed, hydrogenated soybean oil produced growth rates in dairy calves that were comparable to those of calves fed butter oil, whereas crude soybean oil was found to be inadequate. Jacobson et al. (37) indicated that crude vegetable oils such as soybean, corn, and cottonseed oil were unsuitable for milk replacers; however, partially hydrogenated vegetable oils have been used with good results. The digestibility of many animal fats such as tallow, butter, and lard has been greatly improved by homogenization, or the addition of crude soybean lecithin, or both (29, 37, 78). Warner et al. (78) reported the highest utilization of fats when they were homogenized and spray dried.

Several workers (17, 64) have demonstrated that young calves on fat-free diets soon developed symptoms of neuromuscular disease. Unless fat was added to the diet, the calves died. Lassiter et al. (42) fed milk replacers containing 0, 10, 20, and 30 per cent cottonseed fat, modified Marcol B-75, to dairy calves until 56 days of age. The calves also received slightly less than 2 kg of whole milk daily the first 14 days and a calf starter plus hay after one week of age. There was no significant difference in the growth rates of the calves at 56 and 86 days of age. Olson and Williams (57) fed milk replacers composed of dry skimmilk solids and 0, 5, 10, 20, or 30 per cent stabilized lard to dairy calves until weaned at 42 days of age. At 42 days, the average daily gains were 0.34, 0.36, 0.39, 0.39, and 0.42 kg for the calves fed the 0, 5, 10, 20, and 30 per cent fat replacers, respectively. Dry feed consumption decreased as the level of fat in the liquid diet increased. The scouring rate was highest for the calves on the low-fat diet, whereas no significant difference was observed for the other groups. Warner et al. (78) indicated that milk replacers fed to veal calves should contain at least 10 per cent and preferably as high as 25 per cent fat to produce the highest quality veal. Nevertheless, good growth rates have been obtained from milk replacers that contained fat levels of two and six per cent (37, 78). In these studies, the calves consumed more dry starter to compensate for the lower energy intake via the low-fat milk replacers.

The value of many specific nonmilk proteins used in milk replacers has not been satisfactorily determined (36, 37). Jacobson et al. (37) reported good digestibility values for milk replacers in which corn distillers dried solubles provided up to 35 per cent of the protein. Noller et al. (54) reported that milk replacers composed largely of plant products with approximately 33 per cent soybean flour produced little growth until after the calves were approximately 25 days of age. A later study (55) showed that the digestibility of these replacers, and especially the digestibility of the crude protein portion, was low until the calves were more than 25 days of age. Lassiter et al. (44) found that growth rates of dairy calves decreased significantly as the amount of low-fat milk solids in milk replacers decreased from 70 to 15 per cent and the amount of soybean flour and cerelose increased to 28 and 43 per cent, respectively. The milk replacers contained approximately 19 per cent crude protein and from 0.9 to 2.1 per cent fat. Significant differences in growth rates were observed for both the initial 49- and 72-day weighing periods. Stein et al. (71) substituted soybean flour for nonfat dry milk solids in low-fat milk replacers to a level of 43 per cent with good results. The calves fed the above level of soybean flour had daily weight gains comparable to the calves fed a much lower percentage of soybean flour during the initial 28- and 49-day experimental periods.

The optimum level for milk proteins in milk replacers was reported to range from 19 to 24 per cent on a dry matter basis, when growth and protein efficiency were considered (9, 16, 34, 41). Several workers (9, 16, 41) indicated that calves fed milk replacers containing approximately 24 per cent protein had growth rates comparable to calves fed much higher levels of protein. In contrast, calves fed milk replacers containing less than 19 per cent protein showed significantly lower growth rates and protein efficiency (16, 34, 41). Canadian workers (9, 16) found that the per cent dietary protein required by calves fed purified and "filled milk" diets varied with the level of energy intake and growth rate. The protein and energy requirements for maintenance of calves less than two months of age were estimated to be 408.1 mg and 44.7 digestible Calories per kilogram body weight per day, respectively. For 100 g of body weight gain, 20.12 g of protein and 268 digestible Calories were required. The predicted growth rates of the calves, calculated from the protein and energy requirements for growth, compared closely with the actual growth rates. Jacobson et al. (36, 37) stressed the importance of considering the entire diet when determining the optimum level of the various nutrients to be used in milk replacers.

Development of the Rumen

Recent reviews (48, 77) of the anatomical and physiological development of the ruminant stomach indicated that the rumen of the newborn calf was essentially nonfunctional with undeveloped structural characteristics and low metabolic activity. Bryant et al. (12) reported a gradual establishment of the rumen microbial population in young calves. This review of rumen development in young calves will be limited to the structural, microbial, and metabolic development.

Structural Development. Warner and Flatt (77) reviewed the anatomical development of the rumen and reported that the approximate capacity of the reticulo-rumen of newborn calves has been estimated by standard water-filling procedures to be between 0.5 and 1.6 liters.

From this review, it was concluded that the rumen of calves fed concentrate and hay diets had increased in capacity sufficiently that at 12 to 16 weeks of age its proportion was similar to that of the mature ruminant. Several workers (22, 27, 74, 77) have reported that rumen capacity was greatly increased by hay, grain, shavings, and plastic sponges. In contrast, the rumen capacity of calves fed liquid diets has generally increased little with age. Since the rumen was never found to be filled with the above materials, it was postulated that the increased capacity of the rumen was due to the weight of the material within the rumen rather than the bulky nature of the ruminal material (74, 77).

Several investigators (22, 70, 73, 77) have indicated that the muscle layers of tissue of the rumen and also total ruminal tissue, per unit of body weight, of milk fed calves remained relatively constant with age of calves. However, calves which have received solid materials in the form of hay, grain, inert shavings, and sponges have shown marked development of the rumen muscle tissues. The increase in muscle tissue of the rumen of calves which consumed inert material suggested that the work necessary to support and move the ingesta resulted in growth of the muscle tissue.

In a series of studies on the dietary factors influencing the development of the rumen, Cornell workers (22, 27, 67, 77) suggested that the most important stimulus for the development of the rumen mucosa, particularly rumen papillae, was an active rumen fermentation. Certain end-products of rumen fermentation, volatile fatty acids (VFA), rather than coarse materials, appeared to be the specific stimuli. Calves fed grain, hay, or high enough levels of VFA showed a marked increase in the development of rumen papillae with age. Calves fed only milk had little papillary development at any age. Calves fed milk plus shavings have shown extensive muscle tissue growth with little or no mucosal tissue growth in the rumen. Smith (70) reported similar results with calves fed milk plus shavings diets.

Harrison et al. (27) reported a retrogression of rumen papillae when 16-week-old calves on a high hay or grain diet were changed to a milk diet. These workers postulated that rumen mucosal and muscular development were independent as evidenced by (a) an extensive muscular development in the absence of mucosal development when calves were fed shavings; (b) a more rapid retrogression of the reticulo-rumen mucosa than of the reticulo-rumen muscle; and (c) a lower nitrogen percentage in well developed mucosa than in muscle tissue, when expressed on a fat-free dry matter basis (13.3 and 15.1 per cent, respectively).

In an extensive study, Tamate et al. (74) obtained results which were in rather close agreement with those reported earlier by the Cornell workers. Their findings have confirmed the significance of VFA as stimulating entities in the development of the rumen mucosa. Calves fed milk, grain, and hay had well developed rumen papillae and a pigmented rumen epithelium. Marked papillary growth in the rumen was observed in calves fed 61 and 63 moles ot butyric and propionic acid, respectively, over an eight-week period. Typical papillary growth did not occur in calves given approximately 30 moles (2.5 kg) of either butyric acid or a mixture of acetic and propionic acids. Gilliland et al. (26) reported a moderate degree of papillary development in calves that had an estimated 35 and 43 moles of propionic and butyric acids available in the rumen for stimulation of papillary growth over a seven-week period. The mucosal papillary growth of the rumen stimulated by the substitution of VFA for hay and grain was essentially identical, macroscopically as well as microscopically, to the papillary growth observed in calves fed a normal diet (77).

McGilliard et al. (48) reviewed the work conducted at the Iowa station on the relationship between the absorptive ability and the structural development of the rumen mucosa of young calves. These workers observed little rumen mucosal papillary development and a low maximum absorption rate of infused VFA in all calves at one week of age. No significant increase in either papillary growth or absorption rate was found in milk-fed calves from 1 to 34 weeks of age. Conversely, both increased markedly in calves fed solid feed shortly after birth or at 19 weeks of age, which indicated that diet and not age was the crucial factor. The low absorption rate in very young calves and in milk-fed calves was believed to be either directly or indirectly related to the immature status of the rumen mucosa.

Swanson and Harris (73) noted that the newborn calf did not ruminate, and that calves fed only milk did not ruminate. On diets containing dry feed, calves were observed to ruminate at five to seven days of age, but spent less than one hour per day ruminating. Rumination was noted in most calves by two weeks of age. Tamate et al. (74) reported that all calves that received solutions of VFA began ruminating at about seven days of age. Similarly, Gilliland et al. (26) indicated that of 16 calves observed all were ruminating by 11 days of age. Rumination time was positively correlated with dry feed consumption, but less time per kilogram of feed consumed was spent ruminating as the calves aged (26, 73).

Microbial Development. Several workers (11, 12, 42, 46) have reported that the predominant bacteria found in the rumen of calves less than three weeks of age were mainly different from those in the rumen of mature cattle. In an extensive study with young calves fed pasteurized milk for 60 days and free-choice calf starter and hay after nine days of age, Bryant et al. (12) isolated many groups of ruminal bacteria from the calves at six weeks of age that were typical of mature animals. However, several groups typical only of calves remained. At 9 and 13 weeks of age, bacteria isolated were primarily those typical of mature cattle.

The number of aerobic bacteria was highest in calves from one to three weeks of age, but declined sharply thereafter (11, 46). Bryant et al. (12) noted that counts of cellulolytic bacteria were similar to those of mature cattle when calves were three weeks of age and rather high at one week. Lengemann and Allen (45) demonstrated that calves on a normal diet had cellulolytic activity that approached the adult level at six weeks of age. They also reported a microbial flora as varied as that of mature cattle in these calves at eight weeks.

It has been demonstrated that both environment and diet have a major role in the establishment of the protozoan population in the rumen of young calves (11, 12, 15, 42, 46). Bryant and Small (11) found no protozoa in calves which had been isolated for 24 weeks. However, the protozoa were readily established by inoculation at all ages. These workers noted that inoculation of calves accelerated the establishment of rumen protozoa but did not hasten the establishment of bacteria typical of the mature rumen unless the calves were raised under rather strictly isolated conditions. Bryant et al. (12) reported that ciliated protozoa were not established in calves, raised under normal conditions, at 13 weeks of age. Lengemann and Allen (45) found small numbers of protozoa in calves fed only milk over a nine-week period. However, for calves fed limited milk plus hay and grain, the number of protozoa increased rapidly and equaled the adult level by about seven weeks of age. High levels of grain intake also inhibit the establishment of protozoa in the rumen (11).

Metabolic Development. McGilliard et al. (48) reviewed the development of metabolic activity of the rumen mucosa and found a similar pattern of development in the bovine and ovine species. They indicated that rumen mucosa in a structurally immature state was characterized by low metabolic activity; however, the narrow range and artificial nature of the conditions under which these tissues have been studied and the small number of experiments that have been conducted necessarily limit generalization. The undeveloped rumen mucosa of calves one to two days of age did not metabolize butyrate extensively, whereas tissue from a five-week-old calf that received solid feed metabolized slightly more butyrate than did tissue from mature steers.

Sutton et al. (72) determined the effect of diet on metabolic activity of the rumen mucosa of three calves fed milk (M calves) and three calves fed milk, hay, and grain (MHG calves) for 16 weeks. The mucosa of all MHG calves showed extensive papillary development and was typical of tissue from calves reared on solid feed. In contrast, the mucosa of the M calves was thin with only very small papillae. Two-gram samples of rumen mucosa were collected immediately after the calves were sacrificed at 16 weeks of age. Two hundred micromoles of acetate, propionate, butyrate, an equimolar mixture of these three, or glucose, were added to the samples. Mean uptake of these substrates was 5.9, 29.6, 44.1, 31.5, and 3.8 µmoles/100 mg of dry tissue per three hours, respectively, for the MHG calves. For the M calves the values were 2.9, 5.8, 4.7, 5.8, and 4.2, respectively. The percentage conversion of acetate and butyrate to ketones was 72 and 88, respectively, for the MHG calves. The values for the M calves were 17 and 29, respectively. From the latter figures it was evident that the mucosa of the M calves was much less ketogenic. The greater metabolic rate of the mucosal tissue from MHG calves was reflected in the higher production of ketones as well as in the greater uptake of the VFA as shown above.

The basis for the greater metabolic activity of the mucosal tissue of calves fed solid feed was not clear, but it was evident that metabolic activity of the rumen mucosa was low shortly after birth and increased mainly in association with the structural development of the mucosa (48, 72). Several researchers (48, 67, 72, 74) have suggested that VFA affect the structural development and absorptive ability of the rumen by stimulating the metabolic activity of the mucosa. Sutton et al. (72) supported this hypothesis and suggested that the metabolic activity of the rumen mucosa stimulated structural development directly. However, the relationship between metabolic activity and development of absorptive ability by the mucosal tissue was considered indirect, since the latter was apparently dependent upon the combined effects of structural maturation and increased blood flow in the mucosal tissue.

Esophageal Groove Reflex

Various liquids have been observed to effectively by-pass the rumen in young calves and go directly into the omaso-abomasal cavity by way of the esophageal groove (28, 65, 68, 69, 70). Smith (69) observed no decrease in efficiency of the esophageal groove function in calves fed milk by an open pail for a period of 32 weeks. The amount of milk that entered the rumen of milk-fed calves appeared to be less than five per cent in most cases. In a later study, Smith (70) observed little or no leakage of milk into the rumen in a majority of the calves fed from an open pail. The esophageal groove leakage was not considered to be greatly affected by diet or age up to 16 weeks after birth. The leakage appeared to be a consistent characteristic of certain calves rather than a random occurrence. Schalk and Amadon (68) noted that much of the milk consumed from an open pail passed directly into the rumen of three young calves, whereas milk fed via nipple pail generally by-passed the rumen completely by way of the esophageal groove. They indicated that the milk which had entered the rumen passed slowly into the omasum and abomasum.

Hegland et al. (28) found that whole milk, reconstituted skimmilk, reconstituted whey product, or water caused the complete closure of the esophageal groove in all calves when fed from nipple or open pail during the initial six weeks after birth. It was noted that nipple pail feeding of the above liquids was effective in closing the esophageal groove during the initial 13-weeks, whereas open pail feeding was less effective after six weeks. They also reported that when gelatin capsules of various sizes were given to the calf with a liquid they passed directly into the omaso-abomasal cavity. Conversely, the capsules were generally deposited in the rumen directly when fed alone. Rosser (65) obtained similar results with a pelleted milk replacer fed to a rumen fistulated calf during a 15-minute period at three and four weeks of age. All the pellets appeared to be deposited in the rumen at both ages. In contrast, a liquid milk replacer fed to this calf was observed to completely by-pass the reticulo-rumen by way of the esophageal groove.

Ruminal VFA Concentrations

Rosser (65) determined the concentration of VFA in the weekly three-hour postfeeding rumen samples from dairy calves that were weaned from milk to either a powdered or pelleted form of a milk replacer at one week of age. The powdered replacer was mixed with water and fed as a liquid, whereas the dry pelleted replacer was fed in an open pail. All calves were weaned from the milk replacer to an all-concentrate diet at four weeks of age. For the pelleted replacer group, the total VFA level was 5.5 mmoles/100 ml of rumen fluid during the first week, increased slightly during the second week, increased rapidly to 9.3 mmoles/100 ml during the third week, and reached a peak level of 11.3 mmoles/100 ml during the sixth week. For the powdered replacer group, the total VFA level was 3.0 mmoles/100 ml during the first week, increased to 7.6 mmoles/100 ml during the second week, decreased to 6.7 mmoles/100 ml during the third week, and reached a peak level of 10.2 mmoles/100 ml during the fifth week. The total VFA level in both groups tended to stabilize around 9 mmoles/100 ml during the seventh and eighth experimental weeks. The lower total VFA level noted for the pelleted replacer group during the second week was apparently due to the lower consumption of calf starter and the low intake of pelleted replacer by this group during the second week. The general trend of the total VFA and pH values was consistent with the observation that the pelleted replacer was deposited in the rumen; therefore, a larger amount of the total ration was subjected to rumen fermentation in these calves during the initial four-week period.

Ndumbe et al. (52) found that total ruminal VFA concentration increased with age more rapidly for the calves weaned at 28 days than for control calves fed milk plus starter throughout an 84-day experiment. The total ruminal VFA concentration gradually increased from 7.1 mmoles/100 ml at two weeks to 14.4 mmoles/100 ml at six weeks and remained relatively stable at about 14 mmoles/100 ml through the 12th week for the early weaned group. Conversely, the total VFA values for the control group gradually increased from 7.8 mmoles/100 ml at two weeks to 12.6 mmoles/100 ml at 12 weeks of age. The greatest difference betweeen the groups was observed at six weeks. The peak VFA concentration generally occurred two to three hours after feeding in both groups. Yang et al. (79) fed calf starters, with and without supplemental enzymes, to dairy calves as the sole diet after the calves were weaned from milk at 28 days of age. The total VFA level in the rumen fluid of the calves ranged from 7.1 to 9.6 mmoles/100 ml at 32 days of age, with no significant differences among the diets.

Conrad et al. (15) studied the development of the rumen in 71 Jersey calves fed a variety of pelleted high roughage mixtures containing two parts hay to one part grain. The rations were fed free-choice after the third day and constituted the only feed from the seventh to the 16th experimental week. The average concentration of total VFA in the three-hour postfeeding rumen samples was strikingly similar for all the pellet groups. At one week of age, the calves had an average of approximately 3.0 mmole VFA/100 ml. The level of total VFA increased sharply after the first week as the calves consumed more of the high roughage pellets and reached a maximum level of about 11 mmole/100 ml at six weeks. By the 12th week, the average total VFA level had declined to approximately 10.5 mmole/100 ml. In studies with cows, Balch and Rowland (3) found that a number of high roughage rations generally produced total VFA levels between 9 and 12 mmoles/100 ml, whereas mixed hay and grain rations usually produced from 11 to 14 mmoles VFA/100 ml of rumen liquor.

Several workers (15, 52, 60, 79) have determined the molar proportions of the individual VFA in the rumen fluid of calves at various ages. Otterby and Rust (60) determined the molar percentages of the ruminal VFA in calves that were weaned from milk to an all-concentrate or concentrate plus hay diet at 35 days of age. The three-hour postfeeding rumen samples collected from the third through the 13th week from the calves maintained without hay usually contained 50 to 55 per cent acetic acid, 32 to 38 per cent propionic acid, 8 to 10 per cent butyric acid, and a total of 4 to 6 per cent isobutyric, isovaleric, and valeric acid. These VFA proportions were characteristic of those generally found in ruminants fed high concentrate rations (3, 25, 52, 62, 79). The group fed the concentrate plus hay diet had similar proportions of VFA until the calves consumed approximately 0.23 kg of hay daily at seven to eight weeks of age, after which there was a gradual increase in the proportion of acetic acid and a corresponding decrease in the proportion of propionic acid. At 13 weeks of age, the ratio of acetic to propionic acid was about three to one, which was characteristic of high roughage diets (3, 15, 25). Ndumbe et al. (52) and Yang et al. (79) fed high concentrate rations to early weaned calves and reported VFA proportions that were generally very similar to the values given above for the calves fed the concentrate ration only. Conrad et al. (15) fed young calves a variety of pelleted high roughage mixtures containing two parts hay to one part grain and found that the molar percentages of acetic, propionic, and butyric acid generally ranged from 62 to 70, 18 to 26, and 8 to 12 per cent, respectively.

Ruminal Lactic Acid Concentrations

Otterby and Rust (60) collected weekly rumen samples from calves that were weaned from milk to a starter or starter plus hay diet at 25 days of age. During the three- to eight-week collection period, the three-hour postfeeding rumen samples rarely contained more than 5 mg lactic acid/100 ml of rumen fluid. Rumen lactic acid levels were quite variable and ranged from 0 to 95 mg/100 ml during the one- to five-hour postfeeding period at 9 and 13 weeks. However, peak production generally occurred at one to two hours after feeding and samples taken later than this usually contained very small amounts of lactic acid. Because of the variability of the lactic acid levels, differences between dietary groups were not apparent.

Similarly, Ndumbe et al. (52) reported considerable variation in the ruminal lactic acid concentration of calves that were weaned from milk to an all-concentrate diet at 28 days of age and for the control calves that received milk throughout the 84-day experiment. Except for a few instances in which high levels of lactic acid were found in the rumen samples taken before feeding, the prefeeding concentrations generally ranged from 0 to 5 mg/100 ml. Peak ruminal lactic acid concentrations usually occurred at one to two hours after feeding; however, these concentrations had declined to the prefeeding levels in the samples taken four hours after feeding. The average peak lactic acid levels in the one- to two-hour postfeeding rumen samples were 18.1, 7.5, 7.4, 19.4, and 17.2 mg/100 ml for the control calves at 2, 4, 6, 8, and 12 weeks of age, respectively. The corresponding values for the early weaned calves were 25.4, 5.4, 19.9, 33.2, and 36.0 mg lactic acid/100 ml, respectively. No statistical comparison was made due to the large individual calf variation.

The pattern of ruminal lactic acid concentrations in older cattle has generally been quite similar to that observed in young calves (3, 25, 76). Balch and Rowland (3) fed four cows a variety of hay, silage, pasture, and concentrate diets. However, only traces of lactic acid, less than 1 mg/100 ml of rumen fluid, were found with all diets except those containing large amounts of concentrate. The high concentrate diets produced peak lactic acid levels of 95 to 270 mg/100 ml at one to two hours after feeding, but showed no consistent variation with diet. Only traces of lactic acid were present at five hours after feeding. Similarly, Waldo and Schultz (76) fed four steers a variety of forage and concentrate diets. The hay diets produced peak ruminal lactic acid levels that ranged from 20.2 to 41.4 mg/100 ml at one hour postfeeding, whereas the concentrate and silage diets usually produced a peak level at one-half hour after feeding. A grain mixture was fed along with a basal grass hay ration at the rate of 0, 0.57, 1.13, and 1.70 kg/feeding and these gain levels produced peak lactic acid concentrations of 41.4, 54.0, 39.3, and 57.7 mg/100 ml, respectively. Corn and hay-crop silages produced peak levels of 142.4 and 209.3 mg lactic acid/100 ml, respectively. However, over 50 per cent of this acid was introduced into the rumen as lactic acid in the silage. It was found that 0.45 kg of glucose produced a peak level of 124.2 mg lactic acid/100 ml at one-half hour after introduction into the rumen via rumen fistula, whereas 0.45 kg of cellulose or soluble starch produced no lactic acid during the four-hour period after introduction into the rumen. The prefeeding lactic acid concentration noted for the various diets was usually below 1 mg/100 and the peak level had generally declined to the prefeeding level by four hours after feeding. Correlation analysis of the data indicated propionic acid formation from lactic acid. Similarly, Erken and Reid (19) reported that supplementation of a hay diet with lactic acid resulted in an increased molar proportion of propionic acid in the rumen ingesta of cattle.

Ghorban et al. (25) determined the ruminal lactic acid concentration at 15 intervals after feeding a variety of grain and roughage diets to cattle two years of age or older. The lactic acid concentration in the prefeeding rumen samples ranged from 2 to 4 mg/100 ml. Most of the grain and roughage diets produced peak lactic acid levels between 15 and 26 mg/100 ml within one hour after feeding, and the peak value generally declined rapidly to equal the prefeeding lactic acid level at 80 minutes after feeding. The beet pulp ration produced the highest peak lactic acid level with a value of 73 mg/100 ml at 100 minutes after feeding. Values obtained with the all-alfalfa hay ration ranged from 2.5 to 5 mg/100 ml, but there was no definite pattern during the four-hour postfeeding period.

Phillipson (62) reported a large variation in the ruminal lactic acid concentration of eight lambs that were approximately eight months old when started on rations containing high proportions of flaked maize and different levels of supplemental cobalt. No prefeeding ruminal lactic acid concentration was given, but the rumen samples taken one hour after feeding contained approximately 0.1 to 0.5 meq (9 to 45 mg) lactic acid/100 ml. The peak lactic acid level in the rumen of the lambs that received supplemental cobalt generally ranged from 5 to 7.5 meq (450.4 to 675.6 mg)/100 ml, whereas the lambs on a cobalt deficient diet generally had peak levels of less than 1 meq (90 mg)/100 ml due to low feed intake. The peak lactic acid concentration generally occurred at six to eight hours after feeding and then gradually declined, as determined by rumen samples taken at one- and three-hour intervals after feeding. The introduction of 100 g of glucose into the rumen of two lambs resulted in rapid accumulation of lactic acid with peak concentrations of approximately 3.5 and 5.0 meq (315.3 and 450.4 mg)/100 ml at two hours after introduction, but the peak levels declined rather rapidly to the prefeeding levels. It was suggested that the large variation in the amounts of the flaked maize diets consumed and several types of lactic acid producing microorganisms isolated from the rumen fluid of the lambs may have contributed to the high level and large variation of the ruminal lactic acid concentration. Phillipson also cited some results of earlier studies in which he found peak lactic acid concentrations of approximately 220 and 280 mg/100 ml in the rumen within one hour after the sheep received mangolds or glucose, respectively. These peak levels declined rather rapidly to low levels by five hours postfeeding. Small quantities of lactic acid accumulated in the rumen shortly after 100 g of maltose was administered into the rumen through a rumen fistula. No lactic acid was found in the rumen of sheep after the administration of 100 g of galactose, lactose, starch, or 30 g of cellulose into the rumen. Similarly, Krogh (38, 39, 40) found no significant accumulations of lactic acid in the rumen of sheep after a single dose of 100 g of lactose or starch, while 100 g of sucrose did produce some lactic acid. However, daily increases in the quantity of the carbohydrates administered over a period of time led to an acute acid indigestion associated with large accumulations of lactic acid and a marked change in the microbial population of the rumen.

Briggs et al. (8) fed sheep a variety of diets but found consistent significant accumulations of ruminal lactic acid only after feeding rations with high proportions of wheat starch or molasses. The rations that had high proportions of oats and molasses produced peak ruminal lactic acid concentrations of 90 to 802 mg/100 ml at two to six hours after feeding, whereas the high starch rations produced peak levels of 162 to 1522 mg/100 ml at 8 to 12 hours postfeeding. Contrary to the results obtained by Phillipson (62), these workers found only small accumulations of lactic acid in the rumen of sheep fed diets with high proportions of cracked maize. It was evident that the accumulation of lactic acid in the rumen was influenced by the amount of ration consumed and the length of time the ration was fed before samples were collected.

Bruno and Moore (10) found that the production of lactic acid in bovine ruminal ingesta in vitro was stimulated by large amounts of readily available carbohydrates, which confirmed the in vivo results above. No lactic acid was produced with unheated starch, whereas heated starch produced approximately one-half as much lactic acid as did glucose. Propionate production was stimulated by carbohydrate mixtures in both the presence and absence of lactic acid. Some of the propionate was apparently derived from lactate as demonstrated by studies with tracers. However, at pH 6.3, 35 per cent of the uniformly labeled C-14 lactic acid was converted to acetic acid and only nine per cent to propionic acid. At lower pH values, at which lactic acid often accumulates, it may be metabolized more slowly and may be converted to different products.

Early Weaning Systems

Noller et al. (53) reported that calves were successfully weaned to several types of concentrate and hay diets at 21 days of age. Growth rates for the 22- to 42-day and 8- to 70-day periods ranged from 0.29 to 0.44 and 0.45 to 0.51 kg/day, respectively. The early weaned calves had less fleshing, but all were generally active and in good condition. Cud-inoculation proved to be of little value to these calves. Similarly, Pardue et al. (61) reported that dairy calves were successfully weaned from limited milk to calf starter and hay at 24 days of age. The early weaned calves fed an all-plant starter and hay ration gained an average of 0.64 kg/day to 87 days of age. Both of the above systems appeared to be adequate for calves raised for herd replacement purposes, since growth rates above 0.45 kg/day to 12 weeks of age were considered adequate for this purpose (37, 53, 61).

Several investigators (6, 13, 14, 37, 51, 79) reported that dairy calves were successfully weaned from limited milk or milk replacer at 28 to 35 days of age. Jacobson et al. (37) briefly reviewed several studies and indicated that calves were successfully weaned from milk or milk replacer at about four weeks of age if a high quality calf starter was fed. Yang et al. (79) weaned Holstein calves from milk to several types of calf starter rations at 28 days of age and obtained growth rates which exceeded the Beltsville growth standards (47) for Holstein calves. They found that neither the addition of supplementary enzymes nor steaming of the grains had any appreciable effect on calf starter consumption or growth rate to either 8 or 16 weeks of age. Castle and Watson (13) reported on a comparison between a conventional system and an early weaning system of raising dairy calves. The conventionally raised calves consumed an average of 71.9 liters of milk, 325.5 liters of milk substitute, and 88.4 kg of calf meal (17 per cent crude protein) over a 14-week period. The early weaned calves consumed an average of 18.9 liters of milk, 71.9 liters of milk substitute by 35 days of age, and 117.5 kg of "early weaning cubes" (22.7 per cent crude protein). Dried grass was fed ad libitum to all the calves. The live weight gains were 0.57 kg/day for the calves on the conventional system and 0.54 kg/day for those on the early weaning system. The early weaning system proved to be cheaper both per day and per kilogram of live weight gain.

Pellet Acceptability

Lassiter et al. (43) reported no apparent nutritional advantages for the pelleting of calf starters. When calves were given a choice of starters over the period from 1 to 10 weeks of age, they consumed 9.6 kg of an all-meal starter, 19.6 kg of a part-meal-part-pellet starter, and 25.5 kg of an all-pellet starter. The consumption of the all-pellet starter was significantly higher than that of the other two starters, and the improved acceptability of the starters containing pellets was evident for all age periods. However, the acceptability of all starters was about the same when the calves were limited to only one type of starter. Jacobson et al. (37) indicated that texture, composition, amount of other feeds consumed, and the individuality of the calf itself were factors that affected starter consumption. Calves preferred a coarse-textured meal and one that was not dusty.

Moore (49) reviewed the data on the effects of feeding pelleted forage to young calves. In general, it was reported that pelleting of forages resulted in increased consumption of the forages by young calves. The difference in intake of pelleted and long hay by young calves appeared to be even greater in favor of pelleted hay as the hay became more mature.

to the p.m. feeding the first three days on experiment, at weekly intervals, and the last three days on experiment.

Feeding Procedures

All calves received colostrum from their dams for the first three days after birth. The calves started on experiment at three to five days of age, and started on the experimental ration the following day. The milk replacer used in this study was manufactured in both powdered and pelleted forms. The form of milk replacer to be fed during the experiment was randomly assigned to the first member of each pair. The other member of the pair was then assigned the other form of the replacer. Fresh water was available to the calves at all times. The starter ration (Table I) was fed ad libitum throughout the eight-week experimental period.

The exact composition of the milk replacer used in this study is not known by the author. However, the replacer contained approximately 50 per cent milk solids which included dried whey product, dried whole whey, and dried skimmed milk. The ingredients comprising the remaining solids and the guaranteed analysis of the replacer are given in Table II. The milk replacer pellets were 5 mm in diameter and approximately 13 mm in length.

TABLE I

CALF STARTER RATION

Ingredients	Per Cent
Cubed corn	27.5
Crimped oats	20.0
Wheat bran	8.0
Corn distillers solubles	8.0
Dried Molasses	6.0
Soybean meal (50 per cent)	12.0
Alfalfa crumbles	15.0
Aurofac 10[a]	0.25
Vitamin premix[b]	1.25
Salt	1.0
Defluorinated phosphate	1.0

[a]Contained 22 g of chlortetracycline per kilogram.

[b]Amounts of vitamins and minerals per kilogram of premix: vitamin A, 880,000 I.U.; vitamin D_2, 110,000 I.U.; vitamin E, 3,520 I.U.; riboflavin, 3.52 g; niacin, 3.52 g; thiamine, 3.52 g; d-pantothenic acid, 1.62 g; choline, 229.13 g; vitamin B_{12}, 2.20 g; menadione sodium bisulfite, 0.18 g; biotin, 0.035 g; para-aminobenzoic acid, 2.11 g; inositol, 17.60 g; folic acid, 0.18 g; pyridoxine HCL, 1.76 g.

TABLE II

COMPOSITION OF MILK REPLACER[a]

Component	
Crude protein, not less than	28.0%
Crude fat, not less than	10.0%
Crude fiber, not more than	3.0%
Ash, approximately	9.5%
Chlortetracycline	44.0 mg/kg
Riboflavin, not less than	24.0 mg/kg
Vitamin A, not less than	26,000 U.S.P. units/kg
Vitamin D_2, not less than	6,600 U.S.P. units/kg

[a]Ingredients: Dried whey product, dried skimmed milk, dried whole whey, heat processed soybeans, animal fat, corn distillers dried solubles, riboflavin supplement, dicalcium phosphate, magnesium carbonate, iron sulfate, chlortetracycline, vitamin A palmitate, and vitamin D_2 supplement.

Each calf was weighed prior to the p.m. feeding the first three days on experiment and the average of these three weights was used as the initial body weight from which calculations were made to determine milk and replacer feeding rates. Each calf was fed milk at the rate of eight per cent of body weight and either powdered or pelleted milk replacer at 0.2 kg per 100 kg of body weight during the initial two weeks (Figure 1). During this period, the powdered form of milk replacer was fed in the milk via nipple pail and the pellets were placed before the calf in an open pail. The calves were encouraged to eat the pellets by placing a small amount in their mouths at each milk feeding for the first few days. During the third through the fifth week, the calves were fed 1 kg of either powdered or pelleted replacer per 100 kg of initial body weight. The powdered form of replacer was mixed with

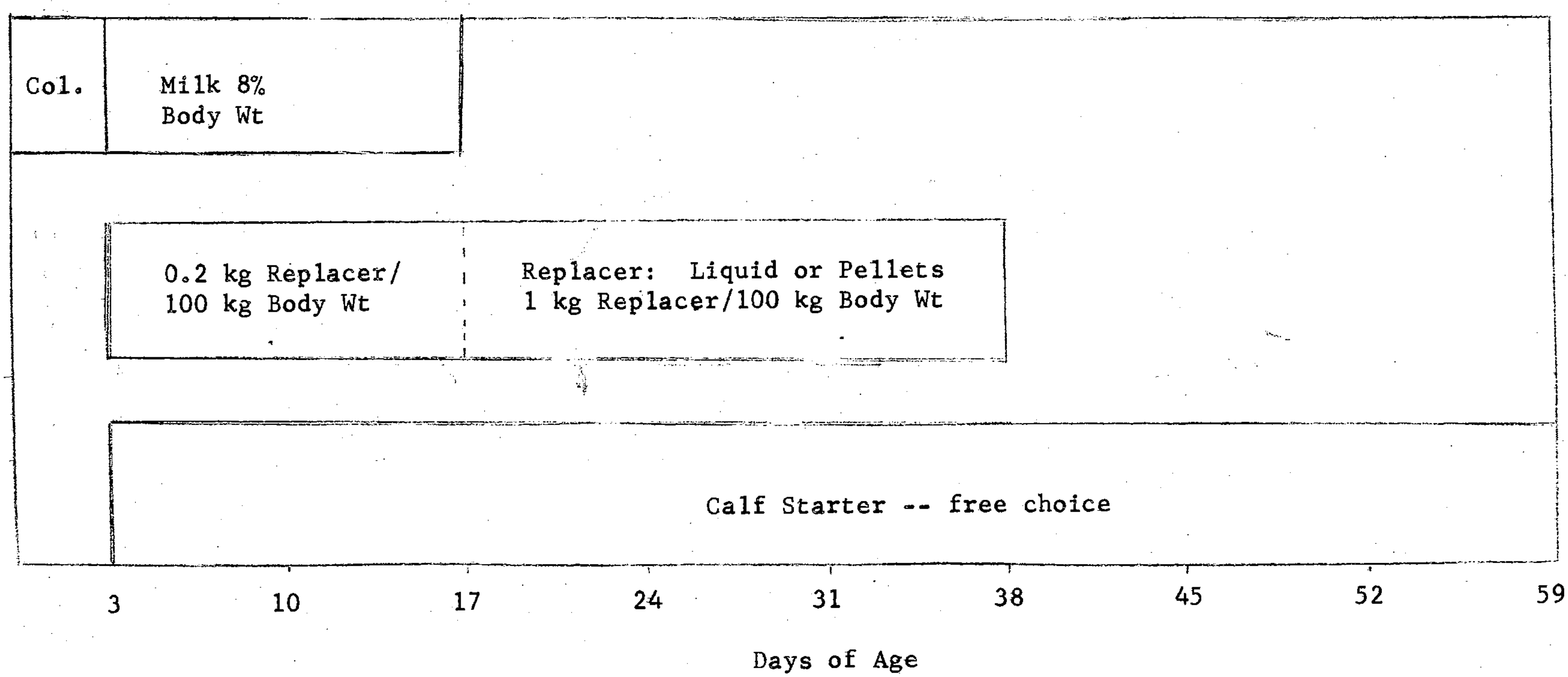

Figure 1. Feeding Regimen Used in Study

water at the rate of 1 kg of replacer to 9 kg of water and fed via nipple pail. (Hereafter, the terms powdered milk replacer and liquid milk replacer will be used interchangeably.) As noted above, the pelleted form of milk replacer was fed in open pails in the same manner as for grain feeding. Consumption of milk replacer and calf starter was recorded on a daily basis for each calf.

Collection of Rumen Fluid Samples

Rumen fluid samples were collected from the calves in both groups at the end of each experimental week. The sample of rumen fluid was taken from each calf at approximately three hours after the morning feeding.

The rumen sampling was done with a stomach pump and tube equipped with a strainer as described by Raun and Burroughs (63). The pH of the rumen fluid was determined immediately using a Beckman Zeromatic II pH meter with a single electrode. The samples were then centrifuged to remove small feed particles. Approximately 50 ml of the supernatant was put into a labeled test tube and frozen for storage.

Determination of Total Ruminal VFA Concentrations by Steam Distillation

The total VFA concentration in the weekly rumen fluid samples was determined by a modification of the method described by Fenner and Elliot (21). A 10-ml portion of centrifuged rumen fluid was put into a distillation flask and adjusted to approximately pH 2.0 by the addition of two drops of 70 per cent (W/V) H_2SO_4. An antifoam agent was also added. The samples were distilled for 20 minutes at a rate which allowed approximately 200 ml of the distillate to be collected. The distillate was titrated to a phenolphthalein endpoint with standardized NaOH(0.031N) to determine the total VFA concentration in the samples. A water blank treated in the same manner as the samples was used to adjust the titration values of the samples. An acetic acid standard (0.0747 N) was used to evaluate the procedure. Recovery of the standard was 99.0 $\pm$ 5.4 per cent (mean and standard deviation).

Determination of Ruminal VFA Concentrations by Gas Chromatography

The individual VFA in the rumen fluid samples were determined using a modification of the gas chromatograph method of Erwin et al. (20). The samples were prepared for analysis by adding 1 ml of 25 per cent metaphosphoric acid to 5 ml of rumen fluid and centrifuging at 3000 rpm for 10 minutes. The supernatant was stored in the refrigerator until analyzed.

The instrument used was an Aerograph Model A-600-C with a hydrogen flame ionization detector. Sensitivity range of one million was available on the instrument through the use of an input range control and an output attenuator. A column, 36 inches long and 1/8 inch in diameter, with neopentylglycol succinate (20 per cent NPGS on 60/80 firebrick treated with three per cent H_3PO_4) was used. The column temperature was maintained at approximately 132°C. An aerograph hydrogen generator model A-650 was used to produce hydrogen from water by the process of electrolysis. Filtered hydrogen (approximately 20 ml/minute) and oxygen (approximately 60 ml/minute) were necessary for operation of the flame ionization detector.

A 5 μliter aliquot of deproteinized sample or VFA standard was injected into the injection block which was maintained at 250°C. The VFA of the samples were eluted using nitrogen (approximately 30 ml/minute) as a carrier gas. Symmetrical peaks of the eluted fatty acids were obtained in approximately 16 minutes, and were recorded by a Sargent Model SR recorder in the following order: acetic, propionic, butyric, and valeric.

A VFA standard solution (Table III) of the above acids was prepared for use in the quantitative determination of the individual acids in the rumen fluid samples. The short chain iso-acids were not included in the VFA standard and no measurement was made of them since rumen fluid usually contains only small quantities of the iso-acids (25, 60).

TABLE III

STANDARD VFA SOLUTION

Acid	g/liter	μmole/5μliters	Mole Per Cent
Acetic	4.3845	0.3651	58.0
Propionic	2.2976	0.1551	24.6
Butyric	1.7786	0.1009	16.0
Valeric	0.1818	0.0089	1.4

The total concentration of VFA in the standard closely corresponded to the average reported level (12 mmole/100 ml) for rumen fluid. The amount of each acid used in the standard was calculated by multiplying the mole percentage of acid usually found in rumen fluid times 12 and then times the millimolar weight of the individual acid. This figure was multiplied by 10 to obtain the weight of each of the acids needed to prepare a liter of standard.

The actual quantity of each fatty acid in rumen fluid was determined from the peak obtained on the recorder. Peak area was calculated as the product of the height of the peak and the width of the peak at half-height in square millimeters. The area of the respective peaks obtained for the individual acids in the rumen fluid samples was divided by the area of the peak for the same acid in the standard VFA solution. This figure was multiplied by the appropriate dilution factor to obtain the millimoles of each VFA per 100 ml of rumen fluid. The total concentration of VFA per 100 ml of rumen fluid was calculated as the total of the four individual acids, and the amount of each acid as a molar percentage of this total was determined.

It was assumed that the peaks obtained after injection of the standard represented the computed number of micromoles per 5 μliters. Several samples of the standard were injected at the beginning and end of the series of rumen fluid samples analyzed each day. A standard sample was also injected after each group of five rumen fluid samples. To minimize errors in the procedure, the standards before and after each group of five rumen fluid samples were averaged to obtain the respective factors used for determining the concentration of individual VFA.

Determination of Ruminal Lactic Acid Concentrations

The lactic acid concentration in the rumen fluid samples was determined by the colorimetric procedure outlined by Barker and Summerson (5). The protein-free samples were prepared by adding 1 to 10 ml of rumen fluid, depending on the anticipated lactic acid concentration estimated from previous weekly samples, to distilled water to make a 16-ml sample. Two milliliter portions of 10 per cent sodium tungstate and 2/3 N sulfuric acid were added. Samples were thoroughly mixed after the addition of each solution and then allowed to stand for 10 minutes before it was filtered with Whatman No. 44 filter paper.

The procedure used for determining lactic acid concentration in the deproteinized samples can be briefly summarized with the following main points. A portion of the filtrate was treated with 20 per cent copper sulfate solution and solid calcium hydroxide to remove other interfering substances such as glucose. An aliquot of the resulting solution was heated with concentrated sulfuric acid to convert the lactic acid to acetaldehyde. The acetaldehyde in the acid solution was determined by its color reaction with p-hydroxydiphenyl reagent in the presence of cupric ions. The absorbancy was determined with a Klett-Summerson colorimeter (Model No. 1019) with a Klett No. 54 filter having a wavelength range of 500-570 mμ and a maximum of 540. The sensitivity of the procedure was reported to be great enough for color development on a sample containing not over 5 to 10 μg of lactic acid per milliliter with differences of less than 0.1 μg per milliliter being readily detectable.

The lactic acid standard was prepared from lithium lactate since this salt is anhydrous. Pure lithium lactate was not available but was prepared as follows: U.S.P. lactic acid (85 per cent) was diluted with an equal volume of water and several drops of phenol red indicator were added. A saturated (approximately 20 per cent) lithium hydroxide solution was added to slight excess, as indicated by the indicator. The solution was heated to boiling and the alkali was again added to slight excess. It was cooled and four volumes of 95 per cent alcohol were added. This solution was then poured into a rotary evaporating flask which was put under vacuum and rotated in a pan of ice water until the lithium lactate crystals were formed. The mass of crystals was filtered off on a Buchner funnel and washed thoroughly with 95 per cent alcohol. This preparation was recrystallized from water and dried at approximately 50°C in the oven. The compound was apparently completely dried since there was no weight loss when it was placed over P_2O_5 in a desiccator under vacuum (60 cm Hg) for several days.

The stock standard solution was prepared by dissolving approximately 0.2 g lithium lactate in distilled water and then adding 1 ml of sulfuric acid and enough water to make 1 liter of solution. The working standard was prepared by diluting 5 ml of the stock standard to 100 ml with water. Both were prepared daily since neither solution appeared to be stable for any longer length of time.

The lactic acid colorimetric procedure was used to construct a standard lactic acid curve from known amounts of lithium lactate in the 1 to 8 ml aliquots of working standard used. The lithium lactate concentration in the various aliquots of working standard was multiplied by 0.938 to convert it to lactic acid. These values along with the corresponding Klett readings obtained by the lactic acid procedure were used to construct the standard lactic acid curve (Figure 2).

As indicated by the standard curve, samples had to be diluted so as to contain not more than 0.012 mg lactic acid per ml in the 10 ml sample at step two of procedure (treatment with $CuSO_4$). This step was chosen because the rumen fluid and standard samples were treated alike after this step. The concentration of lactic acid in the rumen fluid

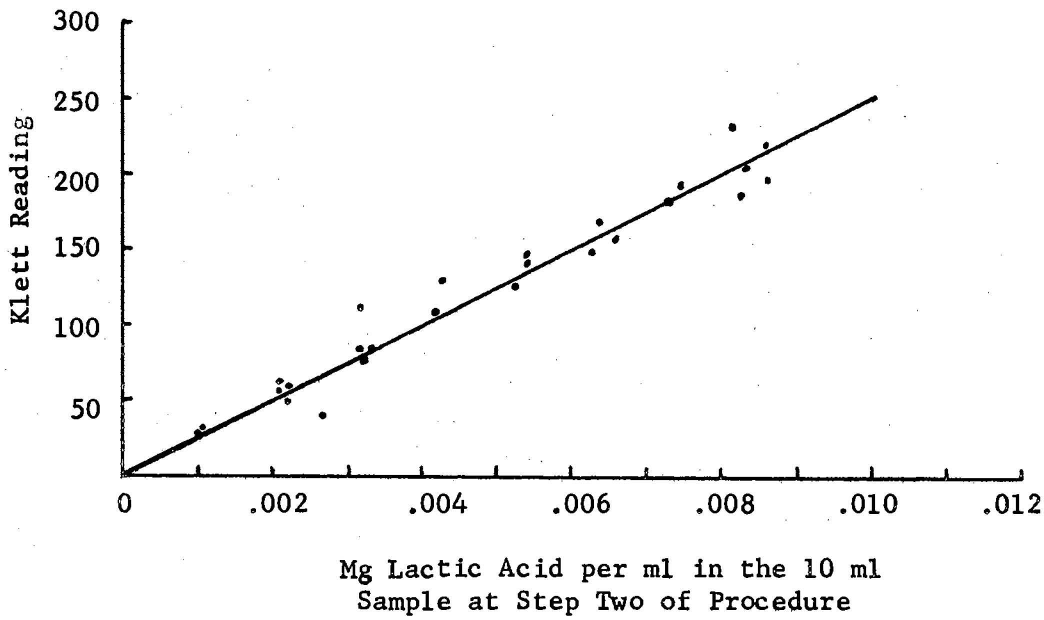

Figure 2. Standard Lactic Acid Curve

samples was determined by taking the Klett reading obtained for the sample and reading the corresponding lactic acid concentration per milliliter of solution at step two of the procedure directly from the standard curve. This value was then multiplied by the proper dilution factors to calculate the concentration of lactic acid as milligrams per 100 ml of rumen fluid.

To standardize the procedure for all rumen fluid samples, two standards, containing approximately 0.02 and 0.08 mg lactic acid, respectively, were analyzed with each group of samples and the average deviation of the two from the standard curve was added to or subtracted from each rumen fluid sample in the group. Duplicate determinations were made on all rumen fluid samples and the average used. Rather extreme precautions were necessary to avoid contamination from outside sources such as lactic acid from the skin or chemicals on the surface of glassware. The use of large test tubes and centrifuge tubes (inside diameter 18-23 mm), where indicated in the procedure, was necessary for rapid thorough mixing of solutions by lateral shaking, and the large tubes were much easier to clean after each analysis.

CHAPTER IV

RESULTS AND DISCUSSION

Feed Consumption

Feed consumption by the calves in this experiment was generally very satisfactory and the calves consumed all of the milk offered to them via nipple pail. There was very little difference in the average total milk consumed by the pelleted and liquid milk replacer groups (Table IV). This reflected the small difference in average initial body weight of the calves in the two treatment groups since the level of milk fed was eight per cent of the initial body weight and no milk was refused by the calves. However, the pelleted replacer group of calves consumed less total milk replacer on a dry matter basis, and there was considerable variation among calves in the amount of pelleted replacer voluntarily consumed. The dry matter content of the pelleted and powdered replacers, as determined by distillation with toluene (2), was 92.2 and 92.5 per cent, respectively. These values were used to convert the respective replacers to a 100 per cent dry matter basis (dry replacer). The pelleted and liquid replacer groups consumed an average of 7.73 and 9.36 kg of dry replacer, respectively, during the entire experiment.

There was a considerable difference between the two groups in average weekly consumption of dry milk replacer and, hence, in the consumption of total milk solids equivalent derived from both the whole

TABLE IV

TOTAL MILK AND MILK REPLACER CONSUMPTION

Pair	Breed	Calf No.	Form of Replacer[a]	Initial Weight	Milk Consumed	Milk Replacer Consumed[b]
				kg		
1	Hol.	92	P	47.6	53.0	9.63
		200	L	46.7	52.1	10.18
2	Hol.	220	P	42.2	47.0	7.81
		67	L	41.3	45.5	9.87
3	Hol.	82	P	43.1	48.3	8.24
		42	L	45.4	50.4	9.98
4	Hol.	48	P	47.2	53.2	8.43
		8	L	44.0	49.3	9.63
5	Hol.	64	P	43.1	48.3	8.76
		219	L	45.4	50.8	10.33
6	Hol.	438	P	49.4	55.5	5.94
		052	L	49.9	55.9	10.98
7	Hol.	655	P	39.9	44.4	8.07
		302	L	38.5	43.2	8.34
8	Ayr.	22	P	34.9	39.4	6.22
		211	L	38.1	43.2	8.34
9	Ayr.	350	P	34.9	39.2	6.65
		097	L	32.7	36.8	7.17
10	Ayr.	244	P	34.0	39.4	7.54
		410	L	40.4	45.7	8.81
	Average		P	41.6	46.8	7.73
			L	42.2	47.3	9.36

[a]P = pelleted replacer; L = liquid replacer

[b]Determined on a dry matter basis.

milk and replacer. The estimated milk solids equivalent consumption was determined by adding the actual weight of the dry replacer consumed to the amount of solids fed as whole milk. The latter amount was obtained by multiplying the quantity of whole milk fed times a milk dry matter conversion factor of 0.11. The Holstein milk fed to the calves contained an estimated 2.5 per cent fat and 11 per cent total solids, since these values were the Holstein herd averages for fat and total solids during the experimental period. The greatest difference between the groups in consumption of estimated milk solids equivalent occurred during the third week of the experiment (Table V). This was obviously due to the lower consumption of the milk replacer by the pellet-fed group after the calves were weaned from milk.

TABLE V

AVERAGE WEEKLY CONSUMPTION OF ESTIMATED MILK SOLIDS EQUIVALENT

Group[a]	Item	Week on Experiment				
		1	2	3	4	5
		kg				
L	Replacer	0.54	0.54	2.76	2.76	2.76
	Milk	2.60	2.60	--	--	--
	MSE[b]	3.14	3.14	2.76	2.76	2.76
P	Replacer	0.12	0.35	2.07	2.50	2.69
	Milk	2.57	2.58	--	--	--
	MSE	2.69	2.93	2.07	2.50	2.69

[a] L = Liquid replacer; P = Pelleted replacer

[b] MSE = Estimated milk solids equivalent

The calves fed the air-dry pelleted replacer usually did not start eating the small amount of pellets, placed before them in open pails, until soon after the first week on experiment. However, several calves consumed all of the pellets (0.2 kg/100 kg body weight) after two days on experiment. Immediately after the calves were weaned from whole milk to 1 kg pelleted replacer/100 kg of initial body weight at 14 days, there was a sharp decline in estimated milk solids equivalent consumed by the pelleted replacer group (Figure 3). This group of calves consumed an average of 0.28 kg or less of estimated milk solids equivalent the first four days after they were weaned. After this short period, most of the calves consumed all the pelleted replacer offered to them. However, several calves consumed only about one-half of the pelleted replacer for at least 10 days after they were weaned from milk, and this accounted for the rather flat area of the curve between the 19th and 25th experimental days for the pelleted replacer group. Thus, the period immediately after weaning appeared to be the critical period of the feeding regimen from the standpoint of supplying the calf with readily utilizable nutrients by a pelleted milk replacer.

The decrease in consumption of estimated milk solids equivalent noted in Figure 3 for the liquid replacer group immediately after weaning at 14 days was due to the lower amount of solids fed as no liquid replacer was refused. Before weaning, the calves received whole milk (11 per cent solids) at the rate of eight per cent of body weight and 0.2 kg of powdered replacer (92.5 per cent solids) per 100 kg of weight for an average of 0.45 kg of solids per day. After weaning, the calves received 1 kg of replacer per 100 kg of initial body weight for an average of 0.40 kg of solids per day. This condition also magnified

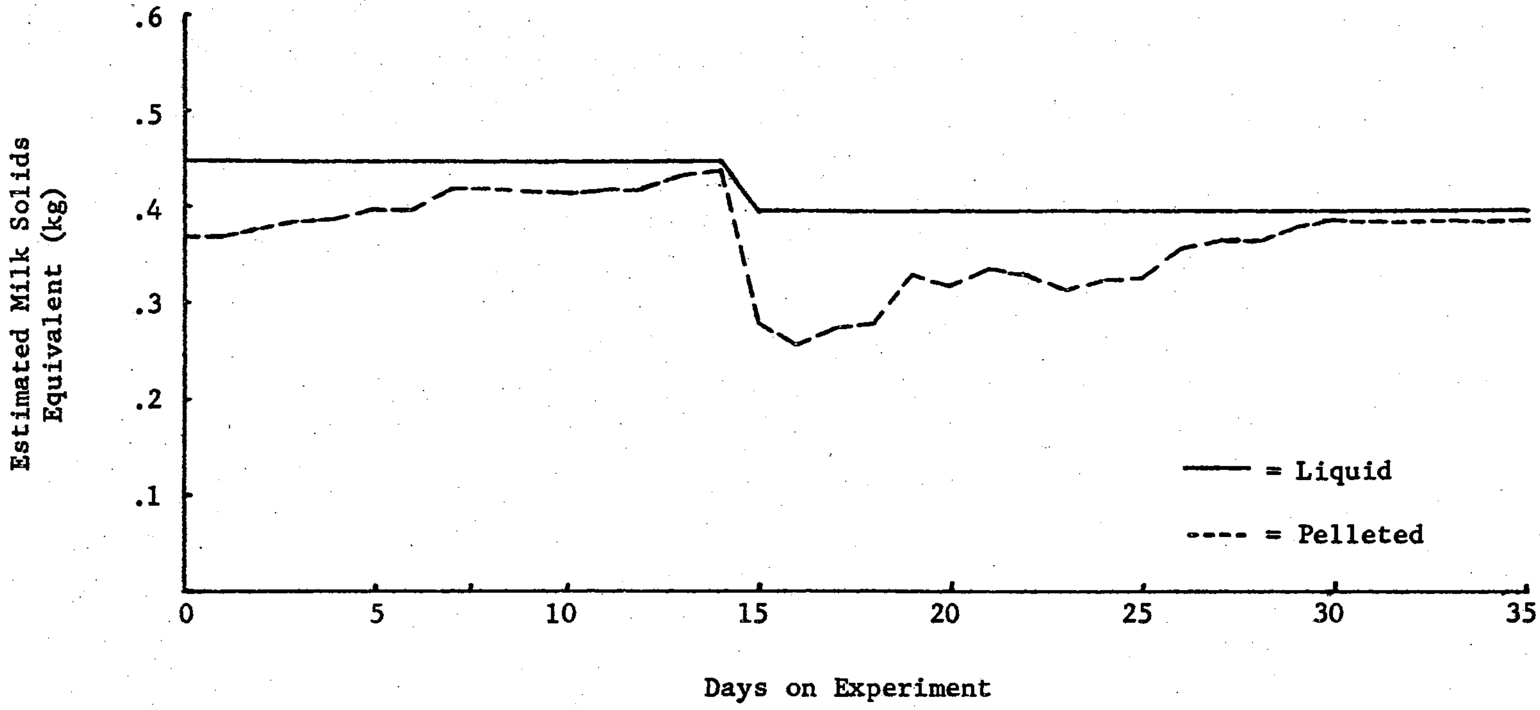

Figure 3. Daily Consumption of Estimated Milk Solids Equivalent

the decrease in consumption of estimated milk solids equivalent noted for the pelleted replacer group immediately after the calves were weaned from milk. The milk solids fed to the calves in the form of whole milk contained an estimated 115 per cent total digestible nutrients as compared to an estimated 96 per cent for the milk replacer. Thus, it was evident that the drop in energy intake was even greater than the drop in solids intake immediately after the calves were weaned from milk. It would have been possible to feed sufficient powdered and pelleted replacer to equal the solids content, and or the energy content, of the whole milk fed during the first 14 days. However, this would have resulted in a greater difference between groups in the nutrient intake from the replacer, and perhaps a greater difference in growth rate. Thus, it is recognized that the comparative growth rates observed in this experiment reflect the experimental conditions imposed.

In a similar study by Rosser (65), calves fed a pelleted replacer were weaned from milk at 10 days of age and the next day the average estimated milk solids equivalent consumed dropped to a low of 0.18 kg. A peak level of pelleted replacer consumption was attained about eight days later and maintained thereafter. The drop in estimated milk solids equivalent consumed immediately after weaning from milk was more drastic than for the calves in the present study wherein milk was fed until 17 days of age.

The group of calves fed the liquid milk replacer consumed more of the calf starter until just after the fifth experimental week than did the group fed the pelleted milk replacer (Table VI). The two groups consumed nearly identical amounts of starter during the second four-week period. However, the liquid-replacer-fed calves consumed an average of 59.1 kg of starter during the eight-week trial as compared to 55.2 kg for the calves fed the pelleted milk replacer.

TABLE VI

AVERAGE WEEKLY CALF STARTER CONSUMPTION

Form of Replacer	Week on Experiment								
	1	2	3	4	5	6	7	8	Total
	kg								
Liquid	0.3	1.3	3.3	4.6	6.8	11.5	15.0	16.3	59.1
Pelleted	0.2	0.5	1.4	3.6	6.6	12.0	14.2	16.7	55.2

The average weekly starter consumption for both groups greatly increased during the sixth week of the experiment as compared to the weeks before and after (Figure 4). The calves no doubt consumed more starter to compensate for the lower energy intake due to the removal of the milk replacer from their diet at the end of the fifth experimental week. A similar increase was previously reported for calves weaned from pelleted and liquid replacers at four weeks of age (65).

There appeared to be no consistent relationship between total pelleted replacer consumption and total starter consumption by the calves in the pellet fed group. However, calf No. 438 consumed the largest amount of calf starter during the third and fourth weeks and also consumed the lowest percentage of pelleted replacer during these weeks (Table VII). This calf apparently compensated for the low pelleted replacer consumption with a higher starter intake. The starter was fed as a coarse-textured meal and was readily accepted by the calves.

Several workers (37, 43) have suggested that a highly palatable calf starter in the form of a meal was not appreciably improved by pelleting.

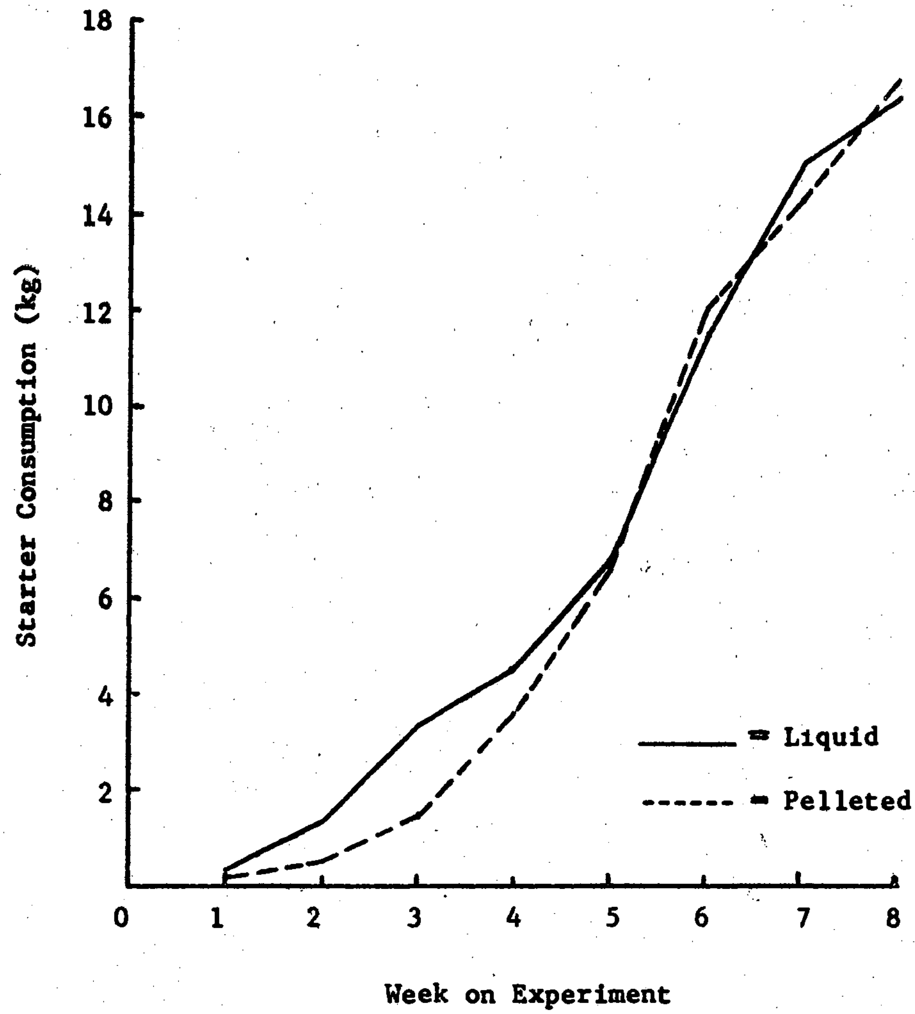

Figure 4. Average Weekly Calf Starter Consumption

Growth and Condition of Calves

The weekly and total weight gains made by the calves in this study were quite variable both within treatment groups and between pairmates. The average weekly weight gains (Figure 5) followed the general trend of estimated milk solids equivalent and calf starter con-

TABLE VII

CONSUMPTION OF REPLACER AND STARTER BY THE PELLETED REPLACER FED CALVES DURING THE FIRST FIVE DAYS

Calf No.	Ration	Week on Experiment 1	2	3	4	5	Total
		kg					
92	P[a]	0.05	0.5	3.0	3.0	3.0	9.6
	S[b]	0.06	0.8	2.3	5.6	11.2	20.0
220	P	0.02	0.2	2.3	2.7	2.7	7.9
	S	0.04	0.4	0.3	0.9	3.2	4.8
82	P	0.07	0.4	2.3	2.7	2.8	8.3
	S	0.5	0.6	2.1	3.1	9.0	15.3
48	P	0.4	0.6	2.2	2.3	3.0	8.5
	S	0.2	1.0	1.3	2.6	6.5	11.6
64	P	0.05	0.5	2.7	2.8	2.8	8.8
	S	0.2	0.8	2.0	6.2	10.7	19.9
438	P	0.05	0.1	0.6	2.0	3.1	5.8
	S	0.03	0.5	2.4	6.4	8.7	18.0
655	P	0.2	0.5	2.0	2.7	2.7	8.1
	S	0.3	0.4	0.1	0.7	1.6	3.1
22	P	0.02	0.2	1.6	2.2	2.2	6.2
	S	0.06	0	1.2	2.5	6.4	10.2
350	P	0.07	0.1	1.9	2.3	2.3	6.7
	S	0.4	0.5	0.5	2.0	4.5	7.9
244	P	0.3	0.4	2.3	2.3	2.3	7.6
	S	0.4	0.4	1.5	5.5	4.7	12.5

[a]Dry Pelleted Replacer

[b]Air-Dry Calf Starter

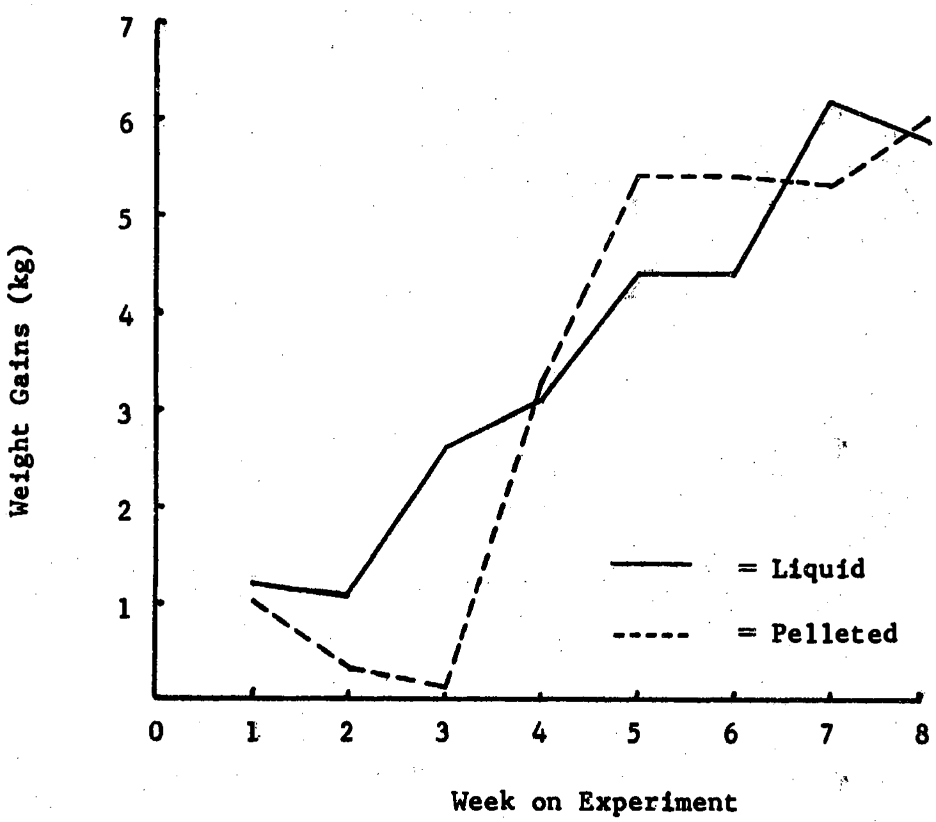

Figure 5. Average Weekly Weight Gains

sumption. The pellet-fed group had an average weight gain of 0.14 kg during the third experimental week which corresponded to the decrease in estimated milk solids equivalent consumed. In the previous study at OSU (65), the pellet-fed group weaned at 10 days of age lost an average of 2.04 kg during the following week. In the present experiment, the decrease in weight gain for the pellet-fed group during the second week can be attributed to several cases of diarrhea observed in this group of calves during the second week. The slight decrease in the weight gain during the seventh week for the group fed pellets was due to a large weight loss in one calf during this week. The calf went off feed temporarily, but recovered quickly to gain 4.5 kg during the last week. There was no apparent explanation for the failure of both groups to gain more during the sixth week of the study than during the previous week, as starter consumption had presumably increased sufficiently to make up for the decrease in total digestible nutrient intake caused by weaning of the calves from the milk replacer at five weeks. However, this does indicate that calves can be weaned from a milk replacer at five weeks of age with no decrease in weight gain. The group of calves fed liquid replacer had an average weight gain of 28.8 kg for the eight-week trial as compared to 26.8 kg for the calves fed the pelleted milk replacer (Table VIII). The difference between the groups was not statistically significant ($P > 0.10$).

TABLE VIII

AVERAGE WEEKLY WEIGHT GAINS

Form of Replacer	Week on Experiment								
	1	2	3	4	5	6	7	8	Total
	kg								
Liquid	1.2	1.1	2.6	3.1	4.4	4.4	6.2	5.8	28.8
Pelleted	1.0	0.3	0.1	3.3	5.4	5.4	5.3	6.0	26.8

The average daily gains during the eight-week experimental period were 0.51 kg and 0.48 kg for the calves fed liquid and pelleted milk replacer, respectively. The Beltsville growth standard for Holstein calves was a daily gain of approximately 0.48 kg from birth to 60 days of age. A daily growth rate of approximately 0.45 kg during the first eight weeks was generally considered adequate for calves raised for herd replacement purposes (37, 53, 61).

Growth rates of the calves were closely related to the thriftiness ratings recorded for the calves at four and eight weeks of age. There was little difference between treatment groups in the number of calves in each group given the various ratings as shown in Table IX. In general, the thriftiness of the calves reflected the amount of feed consumed. Only one calf was rated lower than good and this calf was evaluated during a temporary illness at the end of the fourth week. The average thriftiness ratings were nearly identical for the two groups and all except one calf were given a rating of very good at eight weeks. The average rating changed from 3.5 to 4.0 and from 3.5 to 3.9 at four and eight weeks for the calves in the liquid and pelleted replacer groups, respectively. In the previous study at OSU (65), calves weaned from milk at ten days of age and from milk replacer at 31 days of age generally had thriftiness ratings of three or below. It is recognized that the difference between the two studies may have been influenced to some extent by the person evaluating the calves since the thriftiness ratings are strictly subjective measures of the general condition of the calves. The thriftiness ratings assigned to the calves in the present study do indicate that the calves were generally in good or very good condition. Also, the growth and condition of the calves was evidence that calves can be successfully weaned from milk to a dry pelleted replacer at two weeks of age.

The above statement implied that the pelleted replacer fed to the calves in this study was of sufficient quality in terms of ingredient composition, and that the pelleted replacer was broken down during rumen fermentation to products the calves could utilize at this young

TABLE IX

GENERAL THRIFTINESS RATINGS OF CALVES AT FOUR AND EIGHT WEEKS OF AGE[a]

Pair	Calf	Ration	Weeks Rated	
			4	8
1	92	P[b]	4	4
	200	L[c]	3	4
2	220	P	3	4
	67	L	4	4
3	82	P	3	4
	42	L	4	4
4	48	P	3	3
	8	L	4	4
5	64	P	4	4
	219	L	4	4
6	438	P	3	4
	052	L	4	4
7	655	P	4	4
	302	L	2	4
8	22	P	3	4
	211	L	4	4
9	350	P	4	4
	097	L	3	4
10	244	P	4	4
	410	L	3	4

[a]Evaluation Scale

1 = weak
2 = fair
3 = good
4 = very good

[b]Pelleted Milk Replacer

[c]Liquid Milk Replacer

age, or was digested posterior to the rumen. Also, it implied that a calf starter fed simultaneously with the pelleted replacer was at least partially utilized by the young calves. The milk replacer used in this study contained approximately 50 per cent milk solids (Table II). The remaining major ingredients were heat processed soybeans, animal fat, and corn distillers dried solubles. Crude protein and fat levels were not less than 28 and 10 per cent, respectively.

Stein (71) reported good growth rates in young calves fed milk replacers that contained about 50 per cent milk solids and not more than 40 per cent soybean flour. The 28 per cent crude protein level in the replacer used in the present experiment was apparently adequate when fed in conjunction with a calf starter. The optimum level for milk proteins in milk replacers was reported to range from 19 to 24 per cent on the basis of growth and feed efficiency studies (9, 16, 34, 41). Several workers (42, 57) reported adequate growth rates for calves that were fed milk replacers containing 10 per cent animal or plant fat and a calf starter ration.

However, the per cent protein, fat, or total digestible nutrients (TDN), energy, of the milk replacer alone are of questionable value unless the total ration is considered. Therefore, the per cent crude protein and estimated TDN of the total ration consumed by the calves in both groups of the present study were calculated (Table X). Both the per cent crude protein and estimated TDN of the total ration were high during the first weeks due to the high proportion of milk solids consumed, and decreased as starter consumption increased. The weekly crude protein and TDN consumption increased as starter intake increased. The weekly apparent digestible protein and estimated TDN

TABLE X

SUMMARY OF THE AVERAGE WEEKLY ESTIMATED PROTEIN AND TDN CONSUMED AND REQUIRED BY THE CALVES AND THE PER CENT OF EACH IN THE TOTAL RATION

Group[a]	Item	Week on Experiment							
		1	2	3	4	5	6	7	8
L	% Protein of Ration[b]	27.86	25.39	21.95	21.06	20.10	16.90	16.90	16.90
	Protein Consumed (kg/wk)	0.96	1.13	1.33	1.55	1.92	1.94	2.54	2.75
	Protein Required[c] (kg/wk)	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90
	% TDN of Ration[d]	107.92	98.92	80.75	78.50	76.09	68.00	68.00	68.00
	TDN Consumed (kg/wk)	3.71	4.39	4.89	5.78	7.27	7.82	10.20	11.08
	TDN Required[e]	5.26	5.51	5.76	6.01	6.26	6.51	6.76	7.01
P	% Protein of Ration	28.21	27.21	23.52	21.44	20.12	16.90	16.90	16.90
	Protein Consumed (kg/wk)	0.82	0.93	0.82	1.31	1.87	2.03	2.40	2.82
	Protein Required (kg/wk)	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90
	% TDN of Ration	110.96	106.20	84.70	79.47	76.10	68.00	68.00	68.00
	TDN Consumed (kg/wk)	3.21	3.64	2.94	4.85	7.07	8.16	9.66	11.36
	TDN Required (kg/wk)	5.26	5.51	5.76	6.01	6.26	6.51	6.76	7.01

[a]L = liquid replacer; P = pelleted replacer

[b]Based on 29.1, 28.0, and 16.9 per cent crude protein in the whole milk, milk replacer, and calf starter, respectively.

[c]Based on 40.81 g of apparent digestible protein/100 kg body weight per day required for maintenance and 201.25 g of apparent digestible protein/kg weight gain.

[d]Based on 115, 96, and 68 per cent TDN in the whole milk, milk replacer, and calf starter, respectively.

[e]Based on 1.02 kg TDN/100 kg weight per day required for maintenance and 0.612 kg TDN/kg weight gain.

requirements given in Table X were determined for a calf that had an initial body weight of 42 kg and a daily gain of 0.5 kg to eight weeks of age. The nitrogen and digestible energy requirements of calves for maintenance and growth as reported by the Canadian workers (9, 16) were used. The nitrogen and digestible energy requirements were converted to protein and TDN on the basis that protein contained approximately 16 per cent nitrogen and that 1 g of TDN contained approximately 4.38 Calories. The calves in the pelleted replacer group had the lowest intake of crude protein and TDN during the third experimental week. This was consistent with the weight gain observed for these calves during this week. It was evident that the calves in both groups did not consume enough estimated TDN to make a daily gain of 0.5 kg during the first four experimental weeks. Conversely, the levels of TDN and crude protein consumed were considerably above the level needed to make this rate of gain after the calves were placed on the all-concentrat ration at six weeks of age.

Individual and Total Ruminal VFA Concentrations

The level of VFA in the rumen fluid was determined at weekly intervals to obtain a measure of the rumen development in the calves of both the pelleted and liquid replacer groups. The total VFA concentration, as determined by steam distillation, in the rumen fluid of the calves was expressed as millimoles of VFA per 100 ml of rumen fluid (Table XI). The four major ruminal VFA, acetic, propionic, butyric, and valeric, determined by gas chromatography were added to obtain another measure of the total VFA concentration in the weekly rumen samples of both groups (Table XII).

TABLE XI

AVERAGE WEEKLY TOTAL RUMINAL VFA CONCENTRATIONS AS DETERMINED BY STEAM DISTILLATION

Form of Replacer	Week on Experiment							
	1	2	3	4	5	6	7	8
	(mmole/100 ml							
Liquid	3.8	4.9	7.6	8.2	8.4	9.7	9.4	10.1
Pelleted	3.2	5.7	10.4	10.6	10.3	9.6	9.3	9.9

TABLE XII

AVERAGE WEEKLY TOTAL RUMINAL VFA CONCENTRATIONS AS DETERMINED BY GAS CHROMATOGRAPHY

Form of Replacer	Week on Experiment							
	1	2	3	4	5	6	7	8
	(mmole/100 ml)							
Liquid	4.1	4.8	9.3	7.6	8.3	9.5	10.9	10.5
Pelleted	2.8	6.5	8.8	9.3	12.2	10.5	11.3	10.3

The higher level of total VFA noted for the liquid replacer group at the end of the first experimental week was apparently due to the larger amount of calf starter consumed by this group during the first week, since the liquid replacer by-passed the rumen by way of the esophageal groove (28, 65). During the second through the fifth week, the pelleted-replacer-fed calves consistently had higher levels of total VFA. This was consistent with the observation that the pellets were deposited in the rumen, and subjected more of the total diet to fermentation.

It was also evident that the pellet-fed calves had peak ruminal VFA levels by the fourth or fifth week, whereas the liquid-replacer-fed calves had peak VFA levels from two to three weeks later. There was very little difference between the two groups in total VFA concentration after the replacer was removed from the diet at the beginning of the sixth experimental week. Both methods of total VFA determination showed similar patterns for the average level of total VFA in the weekly rumen samples of both groups during the eight-week period; however, there was less individual deviation from the group mean when the steam distillation procedure was used.

In a similar study by Rosser (65), the pelleted-replacer-fed calves generally had higher levels of total ruminal VFA than did the liquid-replacer-fed calves. Also, as in the present study, the greatest difference between the groups occurred during the milk replacer feeding period. In both studies, the pellet-fed group had a lower starter consumption than the liquid-fed group during the replacer feeding period probably as a result of the deposition of the pelleted replacer in the rumen (65). These facts strongly suggested that the fermentation of the pelleted replacer in the rumen was primarily responsible for the larger accumulations of ruminal VFA in the pelleted-replacer-fed calves during the second through the fifth week. This hypothesis is supported by the fact that there was very little difference between the two groups in total VFA concentration after the replacer was removed from the diet of the calves. Conrad et al. (15) fed dairy calves milk and a variety of pelleted mixtures containing two parts hay to one part grain during the first seven weeks after birth and reported patterns of ruminal VFA concentrations that were similar to those observed for the pelleted-replacer-fed calves of the present study. However, the pelleted-replacer-fed calves in the present experiment did have slightly larger VFA concentrations during the third and fourth experimental weeks, apparently resulted from the larger consumption of readily fermentable carbohydrates in the pelleted replacer. The maximum ruminal VFA concentration occurred at six weeks for the calves fed the high roughage pellets and was comparable to the peak value of the pelleted-replacer-fed calves in the present trial. Ndumbe et al. (52) obtained peak total ruminal VFA levels by collecting hourly samples after feeding and reported a value of 14.4 mmoles/100 ml at six weeks of age for early weaned calves fed an all-concentrate diet, and the peak total VFA level remained at approximately 14 mmoles/100 ml through the 12th week. These peak VFA values are about 2 to 4 mmoles/100 ml greater than the total VFA levels observed in the three-hour postfeeding rumen samples of the present study and by other researchers (15, 65, 79).

The liquid and pelleted replacer groups had similar patterns for the average molar percentage of individual ruminal VFA during the eight-week experiment (Table XIII). It was interesting to note that during the initial two weeks both groups of calves had a wide acetic acid to propionic acid ratio which reflected the type of bacteria present during this period (11, 12). Another point of interest was the higher proportion of butyric and valeric acids and lower proportion of acetic and propionic acids noted for the pelleted replacer group during the third through the fifth week of the experiment. This difference between the groups was apparently due to the deposition of the pelleted replacer in the rumen of the pellet-fed calves, as deposition of the pellets in the rumen has been observed (65) and the highest value for butyric acid

TABLE XIII

AVERAGE WEEKLY MOLAR PERCENTAGES OF VFA IN THE RUMEN FLUID

Form of Replacer	VFA	Week on Experiment							
		1	2	3	4	5	6	7	8
		(molar per cent)							
Liquid	C_2	63.5	57.5	55.3	52.5	52.0	50.2	52.3	50.3
	C_3	28.3	27.2	33.2	37.9	37.4	38.4	39.0	38.2
	C_4	6.8	12.1	8.0	6.5	7.4	8.5	6.0	7.9
	C_5	1.4	3.2	3.5	3.1	3.2	2.9	2.7	3.6
Pelleted	C_2	65.7	60.4	51.2	50.8	47.4	48.6	51.7	51.0
	C_3	22.6	24.4	24.3	31.3	36.2	37.6	37.9	38.4
	C_4	10.5	12.4	19.2	12.4	10.6	10.5	7.3	7.5
	C_5	1.2	2.8	5.3	5.5	5.8	3.3	3.1	3.1

occurred during the third week soon after the calves had consumed large amounts of the pelleted replacer. Also, the pellet-fed calves consumed less calf starter during this period than did the liquid-replacer-fed calves. Recent studies by Bowman and Huber (7) and Rosser et al. (66) provided strong evidence that the relatively high butyric acid levels may be attributed to the lactose in the pelleted replacer. The substitution of lactose for corn in the ration of dairy cows resulted in a significantly higher ruminal butyric acid level (7). The molar per cent of butyric acid in the rumen fluid of steers fed lactose, glucose, and starch was 17.1, 13.0, and 15.3 per cent, respectively (66). Sander et al. (67) reported that butyrate stimulated rumen mucosal development more effectively than acetate or propionate and, hence, the relatively higher butyric acid levels in the pellet-fed calves in the present study implied that the rumen mucosa of these calves developed more rapidly than that of the liquid-replacer-fed calves. Also, ruminal blood flow was increased more by the intra-ruminal infusion of butyric acid than by acetic acid (77). This is consistent with the observation of Smith (70), as he found relatively more rumen development in milk-fed calves that had considerable leakage of milk into the rumen as compared to the calves that had no milk in the rumen.

The ratio of acetic acid to propionic acid became more narrow as the calves in both groups consumed more calf starter during the initial four to five weeks. After the fifth week, there was little difference between the two treatment groups and both had narrow ratios of acetic acid to propionic acid which were characteristic of high concentrate diets.

Otterby and Rust (66) determined the molar proportions of VFA in the rumen fluid of early weaned calves at three hours postfeeding and reported weekly values which were very similar to those observed in the present study. The molar proportions of the individual VFA were relatively constant in the rumen samples taken at hourly intervals up to five hours postfeeding. Ghorban et al. (25) also found that the molar percentages of the VFA changed very little with time in the postfeeding rumen samples taken from mature cattle fed a variety of diets. Ndumbe et al. (52) obtained postfeeding rumen samples from early weaned calves and reported molar percentages of 48, 34, and 17 and 52, 33, and 15 for acetic, propionic, and butyric acid at 4 and 12 weeks, respectively.

Ruminal Lactic Acid Concentrations and pH Values

The lactic acid concentrations in the weekly three-hour postfeeding rumen samples were generally quite variable for the calves in both treatment groups. Due to the large individual calf variation, there was no definite pattern in the average weekly lactic acid concentrations for either the pelleted or liquid replacer groups as shown in Table XIV.

TABLE XIV

AVERAGE WEEKLY LACTIC ACID CONCENTRATIONS IN THE RUMEN FLUID

Group[a]		Week on Experiment							
		1	2	3	4	5	6	7	8
L	Mean (mg/100 ml)	8.7	7.9	2.4	7.1	6.5	6.5	8.5	6.2
	CV[b] (per cent)	182.1	241.5	28.6	157.8	89.0	101.1	118.9	130.2
P	Mean (mg/100 ml)	6.4	20.6	11.6	111.6	125.3	13.0	8.4	10.3
	CV (per cent)	174.2	191.8	163.1	293.9	303.8	121.1	125.9	127.5

[a] L = Liquid replacer; P = Pelleted replacer

[b] CV = Coefficient of Variation

The relatively large coefficients of variation reflected the large and inconsistent variation of the lactic acid concentration in the weekly rumen fluid samples from the individual calves. The unusually high level of lactic acid noted for the pelleted replacer group during the fourth and fifth weeks was due to one calf which had 1044 and 1208 mg lactic acid/100 ml during the fourth and fifth weeks, respectively. During these two weeks, the calf was in good health, consumed 0.42 kg of pelleted replacer daily, and consumed less than 0.25 kg of calf starter daily. Since this calf consumed considerably less calf starter during the fourth and fifth weeks than any of the other pellet-fed calves and less starter than replacer, the large amounts of lactic acid apparently resulted mainly from the rapid breakdown of the readily fermentable carbohydrates of the pelleted replacer in the rumen. It is also possible that the two samples that contained the high lactic acid levels may have been contaminated prior to their analysis. The average lactic acid concentrations calculated for the other nine pellet-fed calves were 7.8 and 5.1 mg/100 ml during the fourth and fifth weeks, respectively.

Large accumulations of ruminal lactic acid have been observed in sheep given readily fermentable carbohydrates (8, 39, 62). Krogh (39) observed marked changes in the rumen microbial population and accumulation of lactic acid associated with indigestion in sheep after the administration of relatively large amounts of lactose into the rumen. Briggs et al. (8) obtained peak ruminal lactic acid concentrations of 90 to 802 mg/100 ml at two to six hours after feeding sheep rations that contained high proportions of oats and molasses, whereas the rations that had large amounts of wheat starch produced peak lactic acid levels of 162 to 1522 mg/100 ml at 8 to 12 hours postfeeding. Phillipson (62) reported ruminal lactic acid concentrations as high as 675 mg/100 ml at six to eight hours postfeeding for lambs fed diets with high proportions of flaked maize. Although the rather high lactic acid values for the one calf fed the pelleted replacer can not be fully explained, the rather low pH values, 4.8 and 5.0, of the rumen fluid were consistent with the high lactic acid values. Since data were available only at three hours postfeeding, it was quite possible that the concentration of lactic acid declined and the pH returned to a normal level prior to the next feeding. This was consistent with the observation (39) that a transitory drop in rumen pH did not result in indigestion. Lactic acid values for the other calves were well below the levels observed to be associated with indigestion in ruminants (1).

Rumen lactic acid concentrations have generally been quite variable for both young calves and older cattle (3, 25, 52, 60, 76). Otterby and Rust (60) found that the ruminal lactic acid levels in early weaned calves ranged from 0 to 95 mg/100 ml, and peak levels generally occurred at one to two hours after feeding. During the three- to eight-week collection period, the three-hour postfeeding rumen samples seldom contained more than 5 mg lactic acid/100 ml of rumen fluid. Similarly, Ndumbe et al. (52) reported peak lactic acid levels of 5.4 to 36.0 mg/100 ml at one to two hours postfeeding, and observed considerable variation in the lactic acid concentrations among early weaned calves fed an all-concentrate diet. The peak lactic acid levels had generally declined to approximately 5 mg/100 ml by four hours after feeding. In studies involving steers and cows (3, 25, 76), a variety of grain, hay, and silage diets have consistently produced peak ruminal lactic acid concentrations in less than one or two hours after feeding. However, there was considerable variation both within and between diets in the rate at which the peak lactic acid levels declined to the prefeeding values. Considering the above results obtained with calves and older cattle and the fact that over 70 per cent of the three-hour postfeeding rumen samples in the present study contained less than 5 mg lactic acid/100 ml, it appeared that the rumen samples from the calves in this study should have been taken closer to the time of feeding to obtain peak lactic acid levels. On the other hand, the samples taken at three hours postfeeding perhaps gave a better indication of whether one can expect lactic acid accumulation to result from fermentation of the milk replacer in the rumen.

The rumen samples which contained high levels of lactic acid consistently had low pH values. When the average weekly pH values (Table XV) were compared with the average weekly ruminal lactic acid and total VFA concentrations, it was found that with few exceptions the pH values varied inversely with the lactic acid and total VFA concentrations.

TABLE XV

AVERAGE WEEKLY pH VALUES OF THE RUMEN FLUID

Form of Replacer	Week on Experiment							
	1	2	3	4	5	6	7	8
Liquid	5.9	6.2	5.8	5.7	5.9	5.6	5.7	5.9
Pelleted	6.2	5.9	5.3	5.3	5.5	5.5	5.9	5.6

The pelleted-replacer-fed group had lower ruminal pH values in all except the first and seventh weeks, but the greatest difference was noted during the milk replacer feeding period from the third through the fifth week. In a similar study at OSU (65), the ruminal pH values for the calves fed the pelleted replacer were consistently below the pH values obtained for the calves fed the liquid replacer, and the largest difference also occurred during the milk replacer feeding period. In both past and present studies, it was found that during the milk replacer feeding period the pH of the rumen contents declined more rapidly and the total VFA concentration tended to increase more rapidly in the calves fed the pelleted replacer than in those fed the liquid replacer. Since the pelleted replacer was observed at three and four weeks of age to be deposited in the rumen of the calves (65), it appeared that the deposition of the pellets in the rumen was primarily responsible for the more rapid increase in rumen fermentation noted for the pelleted-replacer-fed calves during the first few weeks. It was generally recognized that as fermentation was initiated in the rumen there was a buildup of acids and a resultant decrease in the pH of the rumen contents (15, 48). As rumen function became increasingly more efficient this buildup of acids was removed with a resultant increase in pH and a decline in the concentration of the ruminal acids. Thus, even though rumen fermentation increased with advancing age, there was a subsequent rise in rumen pH which was most likely associated with increased absorption of the acids from the rumen as it developed and with an increased buffering capacity of the rumen as a result of increased salivary output (15, 48). Conrad et al. (15) weaned calves from milk to pelleted high roughage rations at seven weeks of age and found that the rumen pH values tended to stabilize within a certain range after the calves were 8 to 10 weeks of age. In the studies at OSU involving pelleted and liquid milk replacers, the rumen pH values were relatively stable after the calves were seven to eight weeks of age.

Several workers (3, 25, 52, 62, 76) have demonstrated that rumen pH was largely a function of the VFA and lactic acid concentrations in the rumen. Rumen pH was depressed more by lactic acid than by any of the individual VFA, due to the higher dissociation constant of lactic acid (25, 52). In an analysis of 260 rumen samples, Waldo and Schultz (76) reported a correlation of -0.33 between the pH values and lactic acid concentrations and a correlation of -0.57 between the pH values and the total VFA concentrations in the rumen samples. Both of these correlations were highly significant at the one per cent level.

CHAPTER V

SUMMARY AND CONCLUSIONS

A study was conducted to compare the performance of 20 male calves, 6 Ayrshires and 14 Holsteins, fed a milk replacer in either pelleted or liquid form under uniform experimental conditions. The performance of the calves was measured on the basis of weekly weight gain; feed consumption; general health and thriftiness; and the pH, VFA, and lactic acid values of the rumen fluid. Whole milk was fed at eight per cent of initial body weight during the first two weeks. The respective replacers were fed at a rate of 0.2 kg solids per 100 kg of initial weight during the milk feeding period and at a rate of 1 kg solids per 100 kg of weight during the third through the fifth week. A calf starter was fed free-choice throughout the eight-week experiment.

There was a slight advantage in favor of the group fed the liquid replacer in terms of average feed consumption and weight gains during the eight-week trial. However, the difference between the groups in weight gains was not statistically significant ($P > 0.10$), and the growth rates of both groups were adequate for calves raised for herd replacement purposes. There was little difference in the general thriftiness ratings for the two groups of calves at four and eight weeks. The critical period of the feeding regimen for the calves fed the pelleted replacer was immediately after weaning from milk at two weeks of age due to a rather low energy intake for several days. The general trend of the ruminal pH and VFA values indicated a more rapid development of rumen fermentation, especially during the third through the fifth week, in the calves fed pelleted replacer. This was consistent with the observation of Rosser (65) that the pellets were deposited in the rumen and, hence, a larger amount of the total ration was subjected to rumen fermentation in these calves. The ruminal lactic acid concentrations were generally low and variable for the calves in both groups. Approximately 70 per cent of the three-hour postfeeding rumen samples contained less than 5 mg lactic acid/100 ml of rumen fluid. The higher lactic acid values were well below the levels observed to be associated with indigestion in ruminants (1).

It was concluded that calves can be weaned from milk to a high quality dry pelleted replacer at two weeks of age with reasonable success under good management conditions when a high quality calf starter is fed. However, further research should be directed toward the practical application of the results obtained in this study before definite conclusions are reached concerning the feasibility of using this product in the field.

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A P P E N D I X

TABLE XVI

DAILY MILK REPLACER CONSUMPTION FOR THE INDIVIDUAL CALVES

Pair	Calf	Ration	Days of Milk Replacer Feeding											
			1	2	3	4	5	6	7	8	9	10	11	12
			kg											
1	92	P[a]	0	0	0	0	0	0	.05	.05	.07	.09	.09	.09
	200	L[b]	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
2	220	P	0	0	0	0	0	.01	.01	0	0	0	0	.01
	67	L	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08
3	82	P	0	0	.02	.03	.01	.02	0	.02	.01	.08	.08	.07
	42	L	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
4	48	P	0	.04	0	.09	.09	.09	.09	.09	.09	.09	.09	.08
	8	L	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
5	64	P	0	0	0	.01	.01	0	.03	.08	.08	.08	.08	.08
	219	L	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
6	438	P	0	0	.01	.01	.03	0	0	.01	.04	.04	.01	.01
	052	L	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
7	655	P	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08
	302	L	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
8	22	P	.01	0	0	0	0	.01	0	0	0	0	.02	.02
	211	L	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
9	350	P	.01	.01	0	0	.02	.03	.02	0	.01	.01	0	.02
	097	L	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06
10	244	P	0	.07	.07	0	.07	.07	.07	.03	.04	.04	.07	.07
	410	L	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XVI (Continued)

Pair	Calf	Ration	Days of Milk Replacer Feeding											
			13	14	15	16	17	18	19	20	21	22	23	24
			kg											
1	92	P[a]	.09	.09	.38	.47	.47	.47	.47	.47	.47	.47	.47	.47
	200	L[b]	.09	.09	.46	.46	.46	.46	.46	.46	.46	.46	.46	.46
2	220	P	.08	.08	.37	.28	.26	.28	.42	.42	.42	.42	.42	.42
	67	L	.08	.08	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45
3	82	P	.08	.08	.34	.34	.33	.34	.37	.39	.43	.41	.43	.43
	42	L	.09	.09	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45
4	48	P	.09	.09	.26	.29	.31	.32	.43	.32	.44	.45	.24	.24
	8	L	.09	.09	.44	.44	.44	.44	.44	.44	.44	.44	.44	.44
5	64	P	.08	.08	.43	.43	.40	.41	.39	.43	.43	.43	.43	.43
	219	L	.09	.09	.47	.47	.47	.47	.47	.47	.47	.47	.47	.47
6	438	P	.01	.03	.31	.03	.10	.03	.12	.04	.04	.10	.15	.24
	052	L	.10	.10	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
7	655	P	.08	.08	.16	.19	.24	.35	.38	.42	.42	.42	.42	.42
	302	L	.07	.07	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38
8	22	P	.07	.07	.29	.26	.18	.17	.26	.28	.28	.34	.34	.34
	211	L	.07	.07	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38
9	350	P	.02	.07	.17	.19	.30	.33	.35	.35	.35	.18	.18	.18
	097	L	.06	.06	.33	.33	.33	.33	.33	.33	.33	.33	.33	.33
10	244	P	.07	.07	.35	.35	.35	.35	.35	.35	.35	.35	.35	.35
	410	L	.08	.08	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XVI (Continued)

Pair	Calf	Ration	Days of Milk Replacer Feeding										
			25	26	27	28	29	30	31	32	33	34	35
			kg										
1	92	P[a]	.47	.47	.47	.47	.47	.47	.47	.47	.47	.47	.47
	200	L[b]	.46	.46	.46	.46	.46	.46	.46	.46	.46	.46	.46
2	220	P	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42
	67	L	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45
3	82	P	.41	.40	.43	.43	.43	.43	.43	.43	.43	.43	.43
	42	L	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45
4	48	P	.24	.39	.44	.47	.45	.47	.47	.47	.47	.47	.47
	8	L	.44	.44	.44	.44	.44	.44	.44	.44	.44	.44	.44
5	64	P	.43	.43	.43	.43	.43	.43	.43	.43	.43	.43	.43
	219	L	.47	.47	.47	.47	.47	.47	.47	.47	.47	.47	.47
6	438	P	.28	.48	.49	.45	.47	.49	.47	.49	.49	.49	.49
	052	L	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
7	655	P	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42
	302	L	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38
8	22	P	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34
	211	L	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38
9	350	P	.18	.18	.17	.17	.35	.35	.35	.35	.35	.35	.35
	097	L	.33	.33	.33	.33	.33	.33	.33	.33	.33	.33	.33
10	244	P	.35	.35	.35	.35	.35	.35	.35	.35	.35	.35	.35
	410	L	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XVII

WEEKLY REPLACER CONSUMPTION FOR THE INDIVIDUAL CALVES[a]

Pair	Calf	Ration	Week on Experiment 1	2	3	4	5	Total
			kg					
1	92	P[b]	.05	.53	2.96	3.04	3.04	9.62
	200	L[c]	.60	.58	3.00	3.00	3.00	10.18
2	220	P	.02	.16	2.25	2.69	2.69	7.81
	67	L	.53	.53	2.93	2.93	2.93	9.85
3	82	P	.07	.40	2.33	2.69	2.75	8.24
	42	L	.58	.58	2.93	2.93	2.93	9.95
4	48	P	.37	.58	2.19	2.28	3.02	8.44
	8	L	.58	.58	2.82	2.82	2.82	9.62
5	64	P	.05	.53	2.68	2.75	2.75	8.76
	219	L	.58	.58	3.05	3.05	3.05	10.31
6	438	P	.05	.14	.62	2.02	3.13	5.96
	052	L	.65	.65	3.23	3.23	3.23	10.99
7	655	P	.16	.53	2.00	2.69	2.69	8.07
	302	L	.47	.47	2.47	2.47	2.47	8.35
8	22	P	.02	.18	1.59	2.22	2.22	6.23
	211	L	.47	.47	2.47	2.47	2.47	8.35
9	350	P	.07	.12	1.89	2.28	2.28	6.64
	097	L	.41	.41	2.12	2.12	2.12	7.18
10	244	P	.33	.36	2.28	2.28	2.29	7.54
	410	L	.53	.53	2.58	2.58	2.58	8.80

[a]Determined on a Dry Matter Basis

[b]Pelleted Replacer

[c]Liquid Replacer

TABLE XVIII

WEEKLY STARTER CONSUMPTION FOR THE INDIVIDUAL CALVES

Pair	Calf	Ration	Week on Experiment 1	2	3	4	5	6	7	8	Total
			kg								
1	92	P[a]	.06	.81	2.31	5.61	11.21	17.99	18.92	19.17	76.07
	200	L[b]	.05	.57	3.14	5.78	6.95	13.22	17.56	18.04	65.31
2	220	P	.04	.35	.33	.90	3.17	9.45	13.95	15.19	43.39
	67	L	.42	1.66	4.57	4.15	8.32	12.73	16.57	17.27	65.69
3	82	P	.49	.64	2.05	3.10	9.02	14.51	19.97	19.58	69.35
	42	L	.28	1.22	4.38	6.07	11.26	16.90	21.59	21.21	82.91
4	48	P	.24	1.00	1.32	2.60	6.45	9.97	14.75	17.19	53.53
	8	L	.14	.59	1.55	4.21	7.01	11.79	18.06	19.18	62.54
5	64	P	.24	.79	2.01	6.15	10.72	15.30	7.28	12.26	54.76
	219	L	.51	.57	2.25	2.49	2.82	3.72	6.68	10.20	29.25
6	438	P	.03	.47	2.40	6.43	8.70	14.73	14.04	20.77	67.58
	052	L	1.19	4.61	8.05	10.61	8.05	14.63	18.92	20.86	86.93
7	655	P	.29	.36	.09	.71	1.59	6.45	12.06	14.90	36.45
	302	L	.22	1.22	3.29	2.92	5.84	10.29	13.41	14.78	51.98
8	22	P	.06	0	1.20	2.45	6.42	12.09	14.94	16.04	53.20
	211	L	.15	1.05	2.89	5.73	7.16	13.86	13.41	16.68	60.93
9	350	P	.43	.50	.46	2.02	4.45	9.11	10.86	13.82	41.64
	097	L	.31	.61	2.01	2.47	4.19	9.04	11.53	13.65	43.82
10	244	P	.39	.41	1.54	5.51	4.71	10.63	14.98	17.89	56.05
	410	L	.12	.41	.75	1.11	6.06	8.77	11.79	10.62	29.61

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XIX

WEEKLY WEIGHT GAINS OF THE INDIVIDUAL CALVES

Pair	Calf	Ration	Week on Experiment 1	2	3	4	5	6	7	8	Total
			kg								
1	92	P[a]	0.9	0	2.3	4.5	7.3	9.1	4.5	5.0	33.6
	200	L[b]	1.8	0.5	1.8	3.6	4.1	5.9	7.3	6.4	31.4
2	220	P	0	0.5	-2.3	0.9	4.1	5.0	7.3	5.0	20.5
	67	L	2.7	0.9	2.7	2.7	4.5	3.2	10.0	5.0	32.6
3	82	P	2.3	0.9	1.4	2.7	7.3	5.2	5.9	5.0	30.9
	42	L	0	1.8	3.6	5.0	8.2	5.9	6.8	6.4	37.7
4	48	P	0.5	0	-0.9	2.3	5.4	1.4	9.1	6.8	24.6
	8	L	-2.3	2.7	1.4	4.1	4.5	8.2	7.3	4.5	30.4
5	64	P	0.9	0.9	5.4	2.3	7.3	8.6	-5.4	4.5	24.5
	219	L	1.4	0	4.1	0	0.5	-0.9	3.2	7.7	16.0
6	438	P	-0.5	0	0	6.4	6.8	6.4	5.0	10.0	34.1
	052	L	2.3	3.8	5.9	4.1	2.7	5.9	7.7	6.8	39.2
7	655	P	1.8	0.5	-4.1	3.2	2.3	2.7	8.6	6.8	21.8
	302	L	2.3	0.5	1.8	1.8	4.1	4.5	6.4	5.4	26.8
8	22	P	1.4	0.9	0.9	1.8	6.8	7.3	5.4	4.5	29.0
	211	L	1.8	-0.5	3.2	4.1	6.4	4.5	1.8	6.4	27.7
9	350	P	0.9	0	-0.9	2.7	5.9	3.6	5.9	5.4	23.5
	097	L	0	0.9	0.9	1.8	2.7	4.5	5.9	3.2	19.9
10	244	P	1.4	-0.9	1.4	5.9	0.9	5.0	6.8	7.3	27.8
	410	L	1.8	1.4	0.9	3.6	5.4	2.7	5.4	6.4	27.6

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XX

WEEKLY TOTAL RUMINAL VFA CONCENTRATIONS OF INDIVIDUAL CALVES AS DETERMINED BY STEAM DISTILLATION

			Week on Experiment							
			1	2	3	4	5	6	7	8
			(mmole/100 ml)							
1	92	P[a]	1.26	5.80	8.55	11.62	11.03	9.93	8.59	9.21
	200	L[b]	1.14	3.08	4.22	8.55	9.12	6.11	8.40	10.71
2	220	P	0.29	3.33	10.04	11.53	8.60	9.52	10.96	10.48
	67	L	2.51	2.76	5.61	7.96	5.93	8.87	7.58	8.59
3	82	P	4.11	5.17	8.65	8.62	11.18	8.37	5.86	6.49
	42	L	3.39	6.14	6.64	9.24	3.70	10.37	6.27	10.65
4	48	P	3.73	7.11	10.68	10.24	9.84	9.77	4.37	9.81
	8	L	4.08	3.86	6.02	5.64	9.21	11.25	6.93	9.37
5	64	P	2.48	5.36	9.59	7.55	10.03	8.27	6.83	9.87
	219	L	5.02	5.55	8.77	9.62	7.71	8.49	10.53	8.87
6	438	P	1.64	4.92	10.46	13.31	10.18	9.96	12.06	9.93
	052	L	6.39	6.80	10.68	7.71	6.74	9.84	8.77	11.33
7	655	P	2.48	3.83	12.75	11.03	12.53	11.47	8.68	12.19
	302	L	2.64	4.58	9.37	7.80	10.81	12.09	11.34	9.90
8	22	P	2.92	4.28	7.05	7.02	4.42	5.64	5.86	10.68
	211	L	2.29	5.27	8.80	11.93	11.84	8.65	8.30	10.03
9	350	P	6.33	9.24	15.66	13.62	14.69	11.78	14.97	10.46
	097	L	3.17	4.99	9.84	6.55	9.06	9.46	11.31	10.06
10	244	P	6.96	8.40	10.90	11.65	10.68	11.72	8.02	10.12
	410	L	7.8	5.61	6.30	7.21	9.74	11.84	14.03	11.25

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XXI

WEEKLY TOTAL RUMINAL VFA CONCENTRATIONS OF INDIVIDUAL CALVES AS DETERMINED BY GAS CHROMATOGRAPHY

Pair	Calf	Ration	Week on Experiment 1	2	3	4	5	6	7	8
			(mmole/100 ml)							
1	92	P[a]	1.75	6.85	8.89	7.21	14.87	5.63	10.54	9.66
	200	L[b]	1.38	2.14	4.66	7.62	14.59	5.86	9.98	10.12
2	220	P	0.81	3.81	9.69	7.24	12.86	5.22	12.65	10.86
	67	L	5.98	2.35	5.76	7.30	4.30	5.96	11.10	11.43
3	82	P	3.60	6.15	4.16	10.88	11.64	8.58	5.37	4.33
	42	L	2.78	5.96	9.41	3.41	2.72	9.83	5.19	12.40
4	48	P	3.19	8.06	11.69	10.71	10.06	9.28	13.37	11.38
	8	L	4.06	4.27	7.53	4.61	9.56	11.49	5.60	7.28
5	64	P	0.88	5.83	8.94	9.32	0.77	10.64	6.52	9.37
	219	L	3.47	5.53	11.92	7.68	4.90	9.91	13.95	11.50
6	438	P	1.27	4.79	12.12	8.52	11.28	10.40	12.62	9.61
	052	L	8.27	5.20	13.39	6.13	6.22	10.30	8.17	11.95
7	655	P	2.19	4.62	5.31	19.47	25.54	20.85	14.16	13.45
	302	L	2.59	4.22	9.36	6.94	10.66	16.36	11.44	10.93
8	22	P	1.83	4.98	5.58	7.04	5.03	8.31	6.92	15.42
	211	L	1.66	5.96	8.31	15.14	9.56	4.24	11.38	6.89
9	350	P	5.45	10.13	13.36	4.07	14.80	10.32	16.76	12.08
	097	L	2.55	5.01	15.49	7.05	9.88	9.39	13.54	11.28
10	244	P	7.44	9.63	8.50	8.78	15.39	16.00	13.58	6.98
	410	L	8.36	7.02	7.11	9.70	10.94	11.29	18.99	10.98

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XXII

WEEKLY MOLAR PERCENTAGES OF VFA IN THE RUMEN FLUID OF INDIVIDUAL CALVES

Pair	Calf	Ration	VFA[c]	Week on Experiment 1	2	3	4	5	6	7	8
				(molar per cent)							
1	92	P[a]	C_2	71.5	54.5	50.8	54.1	45.3	49.8	49.9	47.6
			C_3	23.8	27.8	26.5	28.3	39.7	44.8	40.4	45.5
			C_4	4.7	14.6	20.1	11.1	10.6	3.8	7.0	4.2
			C_5	trace	3.1	2.6	6.5	4.4	1.6	2.7	2.7
	200	L[b]	C_2	70.2	50.4	60.5	43.2	48.7	40.5	47.6	45.9
			C_3	25.8	40.1	27.6	40.5	40.0	51.1	38.6	28.9
			C_4	4.0	7.3	6.4	12.1	8.7	5.6	10.3	15.7
			C_5	trace	2.2	5.5	4.2	2.6	2.8	3.5	9.5
2	220	P	C_2	78.5	56.4	44.6	42.3	40.7	42.5	49.2	45.7
			C_3	13.8	17.4	17.4	27.3	31.2	34.6	40.2	43.5
			C_4	7.7	23.6	27.0	20.5	18.8	20.7	7.4	7.9
			C_5	trace	2.6	11.0	9.9	9.3	2.2	3.2	2.9
	67	L	C_2	51.4	61.9	54.4	56.6	49.9	47.9	55.8	55.6
			C_3	39.9	28.8	33.8	30.8	34.5	32.0	38.6	38.7
			C_4	6.0	4.7	7.5	8.4	10.9	18.2	3.0	4.6
			C_5	2.7	4.6	4.3	4.2	4.7	1.9	2.6	1.1
3	82	P	C_2	47.2	62.6	52.6	44.4	48.8	48.6	62.0	42.9
			C_3	38.7	28.2	21.0	32.8	39.9	19.6	23.3	43.1
			C_4	11.5	9.2	21.2	16.2	6.4	23.3	9.9	10.3
			C_5	2.6	trace	5.2	6.6	4.9	8.5	4.8	3.7

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

[c]VFA Determined were C_2 - Acetic, C_3 - Propionic, C_4 - Butyric, and C_5 - Valeric Acid.

TABLE XXII (Continued)

Pair	Calf	Ration	VFA[c]	Week on Experiment 1	2	3	4	5	6	7	8
				(molar per cent)							
	42	L	C_2	58.0	36.7	46.2	46.2	65.3	51.3	53.8	54.3
			C_3	33.3	28.0	32.4	43.7	21.8	38.5	45.2	34.8
			C_4	7.0	31.9	18.0	7.8	8.2	7.5	.7	7.0
			C_5	1.7	3.4	3.4	2.3	4.7	2.7	.3	3.8
4	48	P	C_2	51.4	53.4	45.9	52.7	47.1	48.3	48.6	54.1
			C_3	32.3	24.5	22.7	35.6	30.2	40.5	42.1	37.1
			C_4	12.6	16.4	23.8	7.9	15.3	8.2	6.6	5.7
			C_5	3.7	5.7	7.6	3.8	7.4	3.0	2.7	2.1
	8	L	C_2	65.9	62.2	64.7	52.8	50.2	51.1	52.1	58.6
			C_3	28.0	16.4	25.1	42.5	40.0	40.9	41.7	35.6
			C_4	5.1	17.1	7.1	3.1	6.5	5.5	4.3	4.3
			C_5	1.0	4.3	3.1	1.6	3.3	2.5	1.9	1.5
5	64	P	C_2	75.3	52.0	56.5	52.2	48.7	43.4	53.8	49.8
			C_3	16.4	38.8	19.7	32.8	35.2	37.3	39.1	41.7
			C_4	8.3	5.5	22.9	10.2	9.1	17.3	4.5	5.4
			C_5	trace	3.7	.9	4.8	7.0	2.0	2.6	3.1
	219	L	C_2	62.7	61.8	59.3	49.6	50.9	52.4	48.6	50.7
			C_3	28.9	27.7	27.6	42.9	40.3	36.8	40.8	42.3
			C_4	8.4	8.1	9.3	4.0	6.1	7.5	7.1	4.2
			C_5	trace	2.4	3.8	3.5	2.7	3.3	3.5	2.8

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

[c]VFA Determined were C_2 - Acetic, C_3 - Propionic, C_4 - Butyric, and C_5 - Valeric Acid.

TABLE XXII (Continued)

Pair	Calf	Ration	VFA[c]	Week on Experiment 1	2	3	4	5	6	7	8
				(molar per cent)							
6	438	P	C_2	74.5	61.2	45.7	50.6	48.2	53.0	49.4	47.9
			C_3	8.2	25.8	32.4	33.6	35.6	38.4	39.7	42.9
			C_4	17.3	10.7	18.5	10.6	9.8	5.0	6.9	5.7
			C_5	trace	2.3	3.4	5.2	6.4	3.6	4.0	3.5
	052	L	C_2	56.4	54.2	49.0	52.6	48.8	53.0	51.7	47.7
			C_3	29.5	33.3	43.9	36.6	41.9	33.2	37.9	41.5
			C_4	11.1	7.9	4.4	8.1	6.0	8.6	5.4	6.7
			C_5	3.0	4.6	2.7	2.7	3.3	5.2	5.0	4.1
7	655	P	C_2	63.3	71.2	50.5	51.3	49.7	53.6	48.7	46.5
			C_3	27.0	21.2	29.8	29.6	34.8	37.0	43.1	41.0
			C_4	8.3	6.7	14.6	14.4	11.8	6.4	5.1	7.6
			C_5	1.4	0.9	5.1	4.7	3.7	3.0	3.1	4.9
	302	L	C_2	60.5	51.4	60.6	57.1	52.6	54.1	50.4	44.2
			C_3	32.9	29.1	29.6	35.1	41.8	38.8	39.9	44.0
			C_4	5.4	17.1	6.3	4.5	3.2	4.7	6.0	7.2
			C_5	1.2	2.4	3.5	3.3	2.4	2.4	3.7	4.6
8	22	P	C_2	73.2	66.6	60.9	52.0	42.6	38.7	50.9	43.9
			C_3	19.5	19.1	20.6	30.6	42.9	55.9	39.8	47.8
			C_4	6.0	11.1	14.3	13.4	9.8	3.9	6.9	6.5
			C_5	1.3	3.2	4.2	4.0	4.7	1.5	2.4	1.8

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

[c]VFA Determined were C_2 - Acetic, C_3 - Propionic, C_4 - Butyric, and C_5 - Valeric Acid.

TABLE XXII (Continued)

Pair	Calf	Ration	VFA[c]	1	2	3	4	5	6	7	8
				Week on Experiment (molar per cent)							
	211	L	C_2	74.4	67.9	49.5	49.9	48.4	47.9	54.7	44.4
			C_3	21.8	21.7	41.3	40.6	41.4	40.6	38.4	47.1
			C_4	3.8	6.5	7.1	6.9	7.4	8.7	4.9	6.4
			C_5	trace	3.9	2.1	2.6	2.8	2.8	2.0	2.1
9	350	P	C_2	67.2	72.2	51.9	53.0	49.3	52.5	49.2	55.6
			C_3	22.7	16.9	25.6	29.6	36.8	33.6	36.6	35.4
			C_4	9.4	8.8	16.4	11.9	8.8	9.5	10.7	6.3
			C_5	.7	2.1	6.1	5.5	5.1	4.4	3.5	2.7
	097	L	C_2	79.4	57.6	41.9	56.6	48.5	50.8	49.9	50.8
			C_3	16.6	24.6	48.3	36.8	42.5	38.2	39.2	27.6
			C_4	4.0	16.1	5.8	4.3	5.8	7.8	8.0	8.9
			C_5	trace	1.7	4.0	2.3	3.2	3.2	2.9	2.7
10	244	P	C_2	54.8	53.7	51.9	55.8	53.6	55.6	55.8	76.0
			C_3	24.1	23.8	27.7	32.7	36.4	34.9	34.9	5.3
			C_4	18.6	17.7	13.1	7.4	5.7	7.4	7.7	15.5
			C_5	2.5	4.8	7.3	4.1	4.3	2.1	1.6	3.2
	410	L	C_2	56.4	70.9	66.5	60.1	57.1	52.8	58.3	51.3
			C_3	26.6	22.1	22.7	29.9	29.9	33.6	29.8	31.0
			C_4	13.0	4.2	7.7	6.0	10.9	11.2	10.2	14.1
			C_5	4.0	2.8	3.1	4.0	2.1	2.4	1.7	3.6

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

[c]VFA Determined were C_2 - Acetic, C_3 - Propionic, C_4 - Butyric, and C_5 - Valeric Acid.

TABLE XXIII

WEEKLY LACTIC ACID CONCENTRATIONS IN THE RUMEN FLUID OF INDIVIDUAL CALVES

			Week on Experiment							
			1	2	3	4	5	6	7	8
			(mg/100 ml)							
1	92	P[a]	0.51	1.39	5.61	2.08	2.56	4.40	8.20	9.60
	200	L[b]	0.63	2.66	1.49	16.00	2.68	4.48	29.10	2.52
2	220	P	0.80	0.62	1.91	3.20	1.76	37.00	37.25	1.87
	67	L	1.04	0.98	1.52	2.48	7.43	1.18	25.40	2.48
3	82	P	2.55	0.75	1.73	1.56	1.82	1.86	4.52	3.56
	42	L	0.95	1.84	1.41	1.78	18.60	2.00	1.93	2.28
4	48	P	1.22	61.60	56.20	46.50	10.50	1.96	1.87	12.20
	8	L	27.60	62.40	2.81	36.70	15.10	23.35	5.00	3.40
5	64	P	1.12	1.07	2.19	9.92	4.96	7.98	11.30	22.26
	219	L	1.52	1.25	2.37	2.45	1.84	3.25	2.76	7.80
6	438	P	0.67	1.39	3.38	2.28	15.00	40.00	5.32	42.80
	052	L	47.20	2.56	3.20	1.76	2.45	10.50	4.00	6.64
7	655	P	0.86	2.01	3.73	1044.00	1208.00	28.80	7.34	5.20
	302	L	0.72	1.16	2.43	3.02	5.09	8.23	9.43	28.55
8	22	P	26.78	119.20	36.00	1.65	1.76	3.00	1.96	2.52
	211	L	4.65	2.10	2.85	2.40	6.42	4.85	1.81	4.97
9	350	P	28.20	15.60	3.34	2.16	3.52	2.20	3.84	1.73
	097	L	0.74	1.42	2.66	2.48	2.88	3.73	2.79	1.76
10	244	P	1.25	2.18	1.51	2.32	2.64	2.32	2.45	1.44
	410	L	2.02	2.93	3.10	2.24	2.72	3.20	3.12	1.93

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

TABLE XXIV

WEEKLY pH VALUES OF THE RUMEN FLUID OF INDIVIDUAL CALVES

			Week on Experiment							
Pair	Calf	Ration	1	2	3	4	5	6	7	8
1	92	P[a]	6.3	6.0	5.4	5.1	5.3	5.7	5.8	5.6
	200	L[b]	6.5	6.4	6.5	5.4	5.6	6.1	5.3	5.2
2	220	P	6.4	5.5	5.2	5.3	6.2	5.5	5.6	5.7
	67	L	6.2	6.5	5.8	5.5	6.0	5.2	5.4	5.7
3	82	P	5.8	6.3	5.5	5.5	5.2	5.4	6.4	5.7
	42	L	6.0	6.6	5.8	6.2	6.7	5.3	6.2	7.0
4	48	P	6.7	5.3	5.2	5.1	5.1	5.1	6.8	5.8
	8	L	5.8	6.9	5.9	5.0	5.7	5.4	5.6	6.1
5	64	P	6.4	6.1	5.4	5.5	5.2	6.1	6.2	5.6
	219	L	6.0	5.6	5.2	5.6	6.1	5.6	6.4	6.4
6	438	P	6.1	6.5	5.4	5.2	5.5	5.7	5.5	6.0
	052	L	5.3	6.1	5.2	6.5	6.6	5.5	6.0	6.2
7	655	P	6.9	6.5	5.2	4.8	5.0	5.1	5.4	5.3
	302	L	5.7	5.7	5.3	5.8	5.2	5.1	5.3	5.1
8	22	P	5.2	5.9	5.2	5.8	6.6	6.0	6.0	5.2
	211	L	5.8	5.8	5.7	5.1	6.0	6.4	5.9	6.1
9	350	P	5.9	5.8	5.2	5.2	5.2	5.1	5.2	5.4
	097	L	5.6	5.8	6.1	5.6	5.7	5.6	5.5	5.8
10	244	P	6.1	5.6	5.5	5.4	5.8	5.4	6.5	5.8
	410	L	5.7	6.6	6.5	6.2	5.8	5.4	5.3	5.8

[a]Pelleted Milk Replacer

[b]Liquid Milk Replacer

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