NUTRITIONAL FACTORS IN CALF DIARRHEA

by

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INTRODUCTION

Nutritional diarrhea is one of the major problems encountered in raising young dairy calves because of their susceptibility to digestive upsets.

This problem has been accentuated through the use of inexpensive whole milk replacers in the diets of dairy calves as early as three days of age. Many calves are being raised successfully on various milk replacement formulas containing animal and vegetable products; however, some of these substitutes have only limited usefulness due to their diarrheic effect.

There is a paucity of information concerning the basic factors involved in nutritional diarrhea even though several dietary constituents have been implicated in the etiology of calf diarrhea. Many reports of the occurrence of nutritional diarrhea are incidental observations made during investigations designed to fulfill other objectives. Much of the work that has been done in feeding milk replacers has been with animals of an age capable of utilizing a more varied diet. Also, the complex milk replacement formulas often used make it difficult to evaluate the relation of any single dietary component to nutritional diarrhea.

If sufficient basic information were available on this problem, milk replacer rations could possibly be formulated in a manner more nearly compatible with the physiological needs of the calf. The research reported here represents a further attempt to obtain additional information concerning the etiology of nutritional diarrhea in young dairy calves. The specific objectives of the present experiment were to study the role of minerals in nutritional diarrhea, to evaluate the role of fat as a costive agent when added to an otherwise diarrheic diet, and to study the relationship of the mineral and fat content of the diet to the rate of passage through the alimentary tract.

REVIEW OF LITERATURE

This review will be limited as far as possible to studies involving the more important dietary constituents apparently associated with nutritional diarrhea in dairy calves during the first three weeks of life. This age span was chosen for the problem under study because the specific character of the diet during this period is more important than at any other time in the life of the calf. The ability of the calf to utilize certain dietary constituents increases after the first few weeks of age. However, where information is limited on very young calves similar information on older calves will be noted.

Some Physiological and Nutritional Events Associated with Diarrhea.

Diarrhea, the frequent passing of fluid feces, has been shown to be associated with decreased absorption and the increased rate of passage of nutritional substances from the alimentary tract. In a summary of data from several experiments with suckling calves, Blaxter and Wood (19) reported that during diarrhea, fecal loss may exceed 40 times the normal daily output and apparent digestibility may decrease to as low as 40% for some nutrients. The ratios of average amounts of water, dry matter, fat, nitrogen and ash in "diarrheal feces" to "normal feces" were 18.2, 7.5, 9.1, 7.5 and 7.1, respectively. Fatty acids accounted for most of the fat loss, while fecal soaps increased less than total fat. The rate of fat passage through the digestive tract was observed (19) with the aid of a lipid stain which appeared in the feces 6 hours after feeding in calves with diarrhea, but not until after approximately 48 hours in normal calves. Cunningham and Loosli (24) observed a greater fecal excretion of neutral fat and free fatty acids associated with a decrease in fecal soaps during a seige of diarrhea in calves two weeks of age. Other workers (40, 91, 97) have shown that vitamin A and carotene are lost in greater amounts during diarrhea, as is vitamin E (19). Undoubtedly, this applies to all of the fat soluble vitamins and possibly to some of the water soluble vitamins. These high losses of dietary entities drastically reduce the nutritional value of the diet.

The fluids and electrolytes of the gastrointestinal secretions are derived from the blood and normally almost all of the electrolytes are reabsorbed. However, when a severe diarrhea occurs, large amounts of gastrointestinal secretions containing chloride, sodium, potassium, bicarbonate and other ions are excreted (36, 98). As the anomaly continues, increased amounts of bicarbonate are secreted into the gut and the rising hydrogen ion concentration in the blood causes a shift in the acid-base balance, producing metabolic acidosis. Excessive loss of minerals by the diarrheic calf wherein calcium and magnesium excretion increased by a factor of 3.7, sodium and potassium by 11.3 and phosphorus by 4.4 has been shown (19). In a young calf exhibiting diarrhea, Blaxter and Wood (17) observed the fecal excretion of ash to increase three times, while the proportions of Ca and P in the ash were not affected.

The magnitude of water loss in severe diarrhea is reflected in the shift from cellular water into extracellular water and dehydration. As fluid continues to be lost, hemoconcentration occurs and the hematocrit, serum sodium and various other blood values begin to rise. Body temperature decreases with extra-cellular fluid reduction and in general they are directly related, provided heat is not gained from the surroundings and infection is not present (62). Dehydration follows water deficit (36) and death usually occurs when 15 to 25 per cent of the body weight is lost.

Relationship of Various Dietary Factors to Nutritional Diarrhea.

Whey

Because of the highly specific nutritive value of lactose for young animals, dried whey and whey product have been used extensively in the formulation of milk substitutes. However, there are numerous reports in the literature of the laxative effect of whey fed to young calves. In general this purgative action of whey has been attributed to its high mineral and/or lactose content, which may be seen in the following comparison with the average compositions of dried whole milk and skimmilk as reported by Morrison (59) and shown in Table I.

TABLE I

THE AVERAGE COMPOSITION OF WHOLE MILK
AND CERTAIN MILK BY-PRODUCTS.

	Dried Whole Milk	Dried Skimmilk	Dried Whey	Dried Whey Product
	%	%	%	%
Protein	24.8	33.1	12.8	15.3
Fat	26.2	1.1	.7	1.3
NFE (Lactose)	40.2	51.1	70.1	59.4
Ash	5.4	8.0	9.2	14.4

Young calves were observed by Brown _et al_. (21) to develop severe diarrhea when gradually changed from whole milk to an all-whey diet reconstituted to contain 10% total solids. Diarrhea ceased entirely within 2 to 4 days after whey was removed from the diet. Wing _et al_. (105) reported that calves had diarrhea after three days of age when fed a semi-synthetic milk containing dried whey product at 27 to 38% of the total solids or 5% of the liquid diet. Also, Young (111) observed diarrhea in calves after four days of age following the isocaloric replacement of 80% of whole milk by whey product or complete replacement of whole milk by whey product and fat. A similar 80% replacement by a combination of whey product, skimmilk solids and fat resulted in a lower incidence of diarrhea.

Murley *et al*. (63) observed severe diarrhea in calves while attempting to make a skimmilk diet isocaloric with whole milk by gradually increasing the concentration of dried skimmilk solids from 10% to a level of 20% over the first nine days of life. However, factors other than the increase in lactose and/or minerals may have contributed to the diarrheic effect of these diets.

More recently, Owen *et al*. (73) observed that whey product, reconstituted to contain 14% total solids, consistently produced a greenish-black watery diarrhea when fed at the rate of 10% live weight to calves from four days of age. Raising the pH from about 4.7 to 7.0 before feeding had no effect on the severity of the diarrhea. In an earlier study (74) analogous results were obtained under similar experimental conditions except that the whey substitute was fed at a lower level and not according to body weight.

Wallace *et al*. (102) and Loosli and Wallace (54) formulated milk substitutes to contain 10, 20, 25, 30, 45, 60 and 70% whey on a dry basis. The substitutes were reconstituted to a gruel consistency and gradually introduced into the diet from seven days of age to replace whole milk within one week. Calves receiving substitutes containing 10 to 30% whey invariably voided moderately loose feces whereas those receiving diets containing larger amounts of whey had diarrhea. As the level of whey in the diet was increased above 30% the diarrhea was noted to be progressively more severe.

However, the milk substitutes in these studies contained varied amounts of other ingredients that apparently are of limited nutritive value to the young calf, thereby making it difficult to determine the purgative effect of the whey. Williams and Knodt (104), though, have reported successful results with a similar type milk substitute containing 10% dried whey fed in the same manner, except that the substitute was reconstituted at a lower dry matter level. Also, Stein _et_ _al_. (99) found 10% whey or 5 to 10% whey solubles to be of benefit when included in similar type milk substitutes fed to replace whole milk at 11 days of age.

Increased utilization of a skimmilk diet was observed by Schmidt and Kliesch (89) following supplementation with dried whey at about 5% of the liquid level. Wise (107) found dried whey to have a therapeutic value for calves suffering from chronic diarrhea and general weakness when fed at a level of 0.5 to 1.0 lb. per 100 lb. live weight. After removing some of the lactose and salts of whey by electrodialysis and centrifugation, Seekles and Wegelin (90) observed no digestive disturbances in sets of identical twin calves fed diets in which 6 or 27% of the protein was from the treated whey. Although the age of the calves was not given, the regular whey was unsuitable for feeding. Also, Daniel and Harvey (25) reported that the feeding of dialyzed whey to rats did not cause diarrhea which did occur when undialyzed whey or dialyzed whey plus the ashed diffusate was fed. Successful results have also been reported (22) from feeding calves whey in which approximately 50% of the lactose is hydrolyzed by the enzyme lactase. More recently a method has been developed by which the mineral content of whey can apparently be controlled but no information on feeding values has been reported (50).

Other workers (26, 57, 86) have reported the successful use of whey in calf diets but in most cases the calves were several weeks of age or had received a considerable amount of milk solids prior to the introduction of whey into the diet. Some differences in the results obtained from feeding whey might be attributed to variations in the individual constituents, such as lactic acid formed by fermentation of lactose and the mineral content which is affected by the length and type of cheese process. Also, the basal ration is a critical factor in the evaluation of the laxative nature of dietary constituents.

Lipids

Early attempts to substitute various fats and oils for butterfat in the diets of young calves were reviewed by Gullickson *et al*. (38) and by Savage and McCay (87). In general, these reviews show that calves fed diets with lard, tallow or butter oil were more thrifty and exhibited less diarrhea than those receiving peanut oil, coconut oil or oleo. Also, calves fed milk substitutes containing pilchard oil, corn oil, cottonseed oil or soybean oil were unthrifty, seriously affected by diarrhea and often succumbed due to the bad effects of the diets. Wise et al. (110) reported severe diarrhea and high mortality among young calves fed soybean oil in contrast to the absence of these anomalies when calves received similar lard-filled diets. Less diarrhea and fewer symptoms of toxicity have been observed (12, 43) when the soybean oil content was reduced from about 3 to 2% in filled-milk diets fed to calves from 4 to 5 days of age, indicating a possible tolerance level. Other workers (2, 11) have shown that feeding fresh soybean oil or corn oil-filled milks prepared daily markedly reduced their morbid effects in comparison to the same products fed after storage.

Hydrogenation of certain vegetable oils, notably soybean, cottonseed and corn oils, has been shown by several workers (3, 11, 64) to be an important factor in their suitability as lipid sources in milk replacers. Calves receiving the hydrogenated oils did not show the severe diarrhea and morbidity observed among calves fed the same unhydrogenated oils. The feeding of highly unsaturated fatty acids, oxidized lard or oxidized butter oil has been associated with the condition of muscular dystrophy in young calves (3, 4, 14). Also, stored hydrogenated soybean oil has been observed (30) to cause more intestinal disturbance than the same hydrogenated oil fed soon after processing. In addition, it appears (11, 64) that regardless of hydrogenation the incidence of diarrhea among calves fed the various lipids increases in the order of butterfat, butter oil, lard, tallow and hydrogenated vegetable oils. Jacobson et al. (43) and Jarvis and Waugh (46) reported that young calves fed filled milk diets containing 3.0 to 3.5% hydrogenated soybean or cottonseed oils exhibited slightly more diarrhea, but had growth similar to calves receiving milk containing butter oil or butterfat. Gullickson et al. (38) observed analogous results when lard and tallow were used as butterfat substitutes. Cunningham and Loosli (24), on the other hand, showed that calves receiving hydrogenated coconut oil from two days of age, at levels of 1 or 2% in liquid purified diets, had a slightly lower incidence of diarrhea than those receiving lard. In contrast to the beneficial results generally reported from hydrogenation of vegetable oils, Ravin and Robinson (81, 82) have recently reported a marked improvement in nitrogen retention when unhydrogenated palm oil replaced hydrogenated palm oil in filled milk diets. No diarrhea was observed when either oil was fed at the 3% level to calves one week of age.

The size of the fat globules has been reported by Bate et al. (12), Huff et al. (42) and by Kastelic et al. (47) to be an important factor in determining the physiological response of the young calf to various lipids. A much lower incidence of diarrhea was observed among calves when vegetable oils were homogenized to reduce the fat globule size in contrast to emulsification or direct addition of the oils into the diet (42, 47). It was also observed (12, 42) that calves receiving unhomogenized oils, including butter oil, had alopecia over the perineal region; however, this condition was never seen in calves which were eating hay and grain (12).

Several workers (11, 38, 46, 64) have reported that blood fat values of calves on various lipid diets were highest for those receiving soybean or cottonseed oils followed, in order, by butterfat, butter oil, lard and hydrogenated soybean or cottonseed oils. Similar blood values were observed by Jacobson et al. (44); however, the relative proportions of the plasma lipid fractions were not altered markedly by the various lipid dietaries. Also, Barker and Jacobson (10) found no marked differences among filled milk diets containing crude or hydrogenated soybean oils, or butter oil with respect to the diurnal variation in the blood plasma fat values of calves. Ramsey et al. (80), on the other hand, observed a longer period of absorption when hydrogenated cottonseed oil was added to skimmilk in comparison to a semi-synthetic diet, and cited work by Huff (41) showing considerable diurnal variation in the plasma fat values of calves fed a semi-synthetic milk containing hydrogenated cottonseed oil. It is apparent from these studies that the plasma lipid level does not necessarily reflect the dietary suitability of a lipid and that the rate of absorption may be affected by other constituents in the diet.

Poor fat digestibility may be considered to have an effect similar to diarrhea because of the related loss of other nutrients. However, the data reported on the digestibility of the various fats and oils have been generally inconsistent except for butterfat. Parrish *et al*. (75) and Noller *et al*. (67) found the apparent digestibility of the ether extract of whole milk to be between 96 and 98% for calves one week and older. Wing *et al*. (105) observed apparent digestibilities of hydrogenated soybean oil, constituting 3% of filled milk diets, to range from 83 to 99% with an average of 92.5%. Adams *et al*. (1) obtained digestion coefficients of 90% for hydrogenated or unhydrogenated corn oil, 89% for lard and 97% for butter oil, when included at a level of 3.5% in filled milk diets fed from 35 days of age. Cunningham and Loosli (48) reported that the digestibility of lard by calves at 2, 4, 6 and 11 weeks of age was about 73, 77, 93, and 94%, respectively, when included at a level of 2% in a liquid purified diet. The digestibility of hydrogenated coconut oil was about 87% for the same periods; however, at 11 weeks a precipitous decline to 72% occurred, which could only be attributed to a shortcoming of the oil. Also, Raven and Robinson (81, 82) observed an increase in the digestibility of hydrogenated palm oil, at 3% in filled milk diets, from 76-86% at two weeks to

92% at three weeks of age. Unhydrogenated palm oil was about 90% digestible at 2 to 3 weeks of age while butterfat was 98% digestible. Cunningham and Loosli (48) cited work by De Man (27) in which soybean oil, hydrogenated soybean oil and butterfat were 67, 75 and 96% digested, respectively. In the partition of the fecal fats it appears that a larger portion was excreted as soaps than as neutral fats and free fatty acids by calves receiving lard or vegetable oils in comparison to those fed butterfat (1, 24, 81, 82).

Several investigations dealing with the dietary requirements of lipids in milk replacers have been reported. Studies cited by Arrington and Reaves (6) and more recent reports reviewed by Roy (84) show that calves have been raised successfully on milk diets containing less than 2% fat after the colostrum period. Adams et al. (2, 3) have raised calves on skimmilk diets having less than 0.15% fat with or without additional milk solids; however, the calves were fed whole milk to 14 days of age. The prevalence of diarrhea among these calves coincides with other recent findings (70, 105) wherein similar skimmilk diets were fed to calves from four days of age. Gullickson et al. (38) fed calves skimmilk from 11 and 20 days of age and observed indigestion only in the younger calves. Also, other workers (6, 60, 45) have reported that certain low-fat diets may adversely affect the health and survival of young calves. Recent studies (24, 51) have also demonstrated that calves fed lipid-free synthetic diets from a few days of age exhibited a greater frequency of diarrhea than controls fed lard or hydrogenated vegetable oils and often died during the first few weeks of age. These studies show that the basic requirements of the calf for fat may be lower than previously assumed, but that some dietary fat in addition to the amount in skimmilk is necessary during the first few weeks of age for normal health and growth.

The appearance of diarrhea among calves on low-fat diets indicated that fat may have a costive effect during digestion. Wing et al. (105) have suggested this role of fat in calf diets and reported that 3% butter oil was more effective in this respect than hydrogenated soybean oil when added to diets of milk solids. Studies by Owen et al. (73) have shown that the inclusion of 3% butter oil in high-lactose and/or mineral diets of milk markedly reduced their diarrheic effects. Also, the homogenization of butter oil into a whey-product diet, tended to delay the appearance of diarrhea several days. On the basis of limited observations, Leighton and Reiser (53) reported that methylated cottonseed oil had more beneficial effects than lard, tallow or butterfat on nutritional diarrhea induced by feeding calves an excess of a control replacer containing 55 lb. dried skimmilk and 45 lb. dried whey. However, 10 lb. of the fatty material being tested was substituted for an equal amount of dried whey which also may have had some effect in reducing the laxative action of the diets. More recently, Lassiter et al. (52) also reported that replacer rations containing 1, 2 or 3% methylated cottonseed oil were effective in reducing the incidence of calf diarrhea. Grimes et al. (37) have observed that young calves fed whole milk diets with 3, 6 or 9% fat had a high incidence of diarrhea on the latter diet only.

It is generally recognized (13) that fat tends to inhibit gastric secretion and motility thereby delaying the emptying time of the stomach. Espe and Cannon (31) investigated this role of fat during digestion in young calves by palpating the curd mass in the abomasum through the rumen and stomach walls via rumen fistula. One liter of skimmilk alone or containing 3 or 6% butterfat, introduced through the reticulo-omasal orifice, required approximately 17½, 14½, and 13 hours, respectively, to leave the stomach. Ramsey et al. (80) proposed a slow passage of fat from the stomach as a possible cause for the delayed absorption of cottonseed oil in reconstituted skimmilk in comparison to a synthetic milk; however, various other factors may also be involved. It is possible that fat may have some inhibitory effect on the stomach of the calf; however, the soft curd produced in its presence would apparently mask the effect, since the degree to which the gastric contents have been reduced to liquid is also an important factor in the time of evacuation (61, 71, 95).

Reasons for the superiority of butterfat in comparison to other fats and oils in the health and growth of young calves have not been identified, but are believed to be associated with the short-chain fatty acids. Undoubtedly the general uniformity of butterfat is also involved. Even when the same type of lipid material is used, various factors such as hydrogenation, melting points, types and lengths of storage and other differences in handling and processing may result in lipids of widely differing nutritional value. Also, it appears that the digestibility of the dietary fat may be related to the age of the calf.

Carbohydrates

Numerous investigators have reported the occurrence of diarrhea in animals fed various amounts of lactose; however, relatively few of these reports have involved dairy calves. Several excellent reviews have appeared on various aspects of this subject, including those of Fischer and Sutton (32) and Duncan (30) dealing with physiological effects of lactose, that of Pierce (78) on the absorption of specific sugars and more recently that of Atkinson *et al.* (9) relative to animal and human feeding.

From a recent review of the literature Atkinson *et al.* (9) concluded that, in general, young dairy calves are able to tolerate extremely high levels of lactose although this tolerance decreases with age. According to Fischer and Sutton (32) an animal may adapt to lactose feeding and diarrhea may even cease entirely if large amounts of lactose are ingested over a period of time. Rojas et al. (83) studied the effect of doubling the lactose content of skimmilk so that the total lactose intake was about 640 g. and 500 g. per day for two calves at 42 days of age. Diarrhea occurred within a few hours after feeding and was accompanied by an increase in urinary galactose equivalent to 8% of the lactose ingested. More recently, Owen et al. (73) found that lactose added at the rate of 5% to whole milk diets had no influence on fecal consistency when the diets were fed at the rate of 8% of body weight to calves at 4 and 11 days of age. However, similar supplementation in reconstituted skimmilk produced moderate diarrhea regardless of the age of the calves when experimental feeding was begun. Also, Blaxter and Wood (19) reported that the dry matter content of the feces decreased proportionately as the glucose and/or lactose content of the diet was increased from 0 to 325 g. per day. In reviewing the work on the nutrition of the young calf, Roy (84) noted that on the basis of a limited number of observations it appears that diarrhea and unthriftiness are associated with intakes of over 250 g. of lactose and/or glucose daily. Flipse et al. (33, 34) observed that calves from two days of age fed a synthetic milk replacer containing 60% glucose (6.3% liquid basis) as the sole source of carbohydrate had very soft to semi-liquid feces. When 10, 30 or

45% of the glucose was replaced with corn syrup the severity of the diarrhea increased, whereas calves maintained a normal fecal consistency when lactose was substituted for 5, 10 or 30% of the glucose in the basal ration. Also, diets containing combinations of starch and glucose produced severe diarrhea which was slightly alleviated by the addition of lactose. From the many reports of lactose-induced diarrhea this anti-diarrheic action of lactose is confusing; however, in a recent review of the literature, Atkinson et al. (9) state that lactose may be used in therapy against both constipation and diarrhea in humans.

More recently, Raven and Robinson (81) reported that a skimmilk diet with lactose added to increase the sugar content of the milk to about 8.5% did not produce diarrhea in calves during an 11-day digestion trial from 4 days of age. Other workers including Ramsey et al. (80) and Noller et al. (66) have fed liquid milk replacers containing 3.5 to 5.5% lactose or 6% glucose to calves a few days of age with no effect on fecal consistency.

Savage and McCay (87) concluded that most of the early studies concerning the utilization of sugars and starches by young calves were complicated by vitamin A deficiencies. In addition, the early method of feeding milk replacers after an extensive whole milk and/or skimmilk feeding period undoubtedly accounts for some of the more beneficial effects obtained when starch, corn syrup and various other carbohydrates were included in milk replacer diets.

In a recent review of the literature, Preston (79) concluded that starch is poorly utilized by very young calves and that at least for the first month of age lactose and glucose are the only suitable carbohydrates for inclusion in a milk replacer diet. Shaw et al. (92) demonstrated that 4 to 7 day old calves were able to digest only 20% of the corn starch added to whole milk diets, but by 3 to 4 weeks of age the calves were able to digest over 90% of the starch. In general, studies (29, 33, 69) show that in calves under six weeks of age solutions of lactose, galactose and glucose produce a rapid rise in blood sugar, while fructose, maltose, sucrose and corn syrup cause only a slight rise with essentially no utilization of starch and dextrin. Also, Velu et al. (101) observed that solutions of sucrose, fructose and maltose produced diarrhea in calves whereas no intestinal disturbance resulted from glucose, galactose or lactose administration.

Protein

Several investigators have noted that calves are subject to diarrhea when fed nitrogen-free or low protein diets. Severe diarrhea was observed (15, 23) in young calves fed semi-purified, nitrogen-free diets to determine their endogenous urinary and metabolic fecal nitrogen excretions. Brisson et al. (20) reported occasional diarrhea in calves, from 3 days of age, fed milk substitutes in which casein or whole milk provided a protein level of about 14% of the dry matter or 2% of the fluid diets. However, in these studies (15, 20, 23) the digestive disturbance could not be attributed entirely to the low protein level or even the absence of protein because of the possible laxative effects of the high glucose or cerelose content of the diets.

Blaxter and Wood (18) reported that the replacement of casein with gelatin caused profuse diarrhea and dehydration, but the gelatin may have contributed to the cause of the anomaly. Also alimentary disturbances were observed (16, 18) to be invariably present in young calves when protein, derived from dried skimmilk or casein, was fed at about 2% of liquid synthetic diets. Roy (84) reports that young calves, particularly under highly infectious conditions, may receive less value from dried skimmilk processed at a high temperature than from fresh skimmilk or dried skimmilk processed at a lower temperature.

Various workers (35, 66, 99) have reported mediocre results in the growth and health of young calves when the major part of the protein in milk replacements was derived from certain sources, i. e., soybean flour, soybean and linseed oil meal, blood meal and distillers dried solubles. Noller et al. (67) observed little or no utilization of soybean flour and distiller's dried solubles in vegetable milk replacers fed during the first three weeks of age but there was no mention of digestive upsets. Wallace et al. (102) observed severe diarrhea when high-fat soya flour was fed as an additional source of protein in a diet already containing 50% dried skimmilk. Also, Shoptaw (94) reported that the use of soybean flour as a complete substitute for milk resulted in poor growth and diarrhea.

Minerals

There appears to be little information in the literature on the addition of minerals to calf diets other than the required amounts and those used as therapeutic agents in calf diarrhea. One-fourth teaspoon of slaked lime (calcium hydrate) added to the diet after the start of diarrhea was reported (21) to be effective in controlling this anomaly in young calves fed all-whey diets. Williams and Jensen (103) observed that calves receiving about 9 g. of calcium caseinate or hydrated lime had firmer feces than calves on a similar diet. According to Winslow (106) solutions of lime are a direct sedative to the stomach and assist in the retention and digestion of milk in the abomasum of young calves exhibiting diarrhea. Milks (74) states that protective, antacid and astringent effects of basic solutions are due to their alkaline action.

Studies (25, 90) showing that diarrhea may be caused by the mineral content of whey have been previously discussed. More recently, Owen et al. (73) observed no appreciable diarrhea when young calves were fed whole milk, butter oil-filled milk or reconstituted skimmilk diets supplemented with minerals, at a level of 2.1%, to simulate the mineral content of whey product. As a further test of mineral laxation, 12 calves were fed additional minerals increased gradually up to 6.3% in their whole milk diet. Only two calves on high-mineral diets showed appreciable diarrhea and after continued feeding of these diets for periods of over 2 weeks the calves were generally noted to have firm feces. It was proposed that the calves may have received some anti-diarrheic effect from the tannic acid content and/or physical action of the wood shavings used as bedding. However, the advance in age and the gradual increase in minerals may have allowed the calves to adapt to the higher levels of mineral feeding. During the second phase of the study, whole milk containing 3% fat and skimmilk diets with minerals added at a level of 2.1% were fed to calves at 11 days of age or older and confined in stalls without bedding. Mineral supplementation had a significant diarrheic effect; however, the short 4-day feeding trials in the Latin square design may have had an influence on the response obtained.

Vitamins

Numerous attempts have been made to fortify calf diets with additional vitamins as a preventative measure against diarrhea. In studies reported by the Wisconsin workers (55, 77), supplementary feeding of vitamins A, C, D and certain members of the B complex to calves during the first few weeks of life prevented nutritional diarrhea and reduced mortality. Also, Hansen _et al._ (39) observed less incidence of severe diarrhea among young calves fed additional vitamin A. However, other investigators (7, 40, 65, 68) have failed to substantiate these findings and reported that the administration of extra vitamins was not beneficial if adequate amounts were already present in the diets.

Coagulation

Lack of coagulation and resulting rapid passage of material through the digestive tract has been suggested as a possible cause of the loose feces condition often associated with the feeding of milk replacers. Williams and Jensen (103) reported that autopsies performed on calves fed milk replacers containing large percentages of milk solids showed little or no milk curds in the abomasum. The addition of hydrated lime to increase coagulation promoted firmer feces; however, lime itself is known to have an anti-diarrheic action. Kastelic _et al._ (34) observed no diarrhea when colostrum-free calves were fed a semi-synthetic milk with a calcium to sodium ratio of 2.5:1.0. On the other hand, severe diarrhea and a high rate of mortality occurred among calves receiving a diet of similar composition except that the ratio of calcium to sodium was changed, 0.8:1.0, to prevent coagulation by rennet. Calves which survived on the low-calcium diet had a gradual decrease in the severity of diarrhea with increasing age. The authors concluded that the coagulation of milk is essential for the well being of very young calves; however, some of the morbid effect observed may have been enhanced by the absence of colostrum. According to Blaxter and Wood (19) diarrhea inevitably results when curd formation is inhibited or excluded by the nature of the diet; however, their observations were made on dissimilar diets without a control. More recently, Owen et al. (72, 73) have reported that the prevention of curd formation by the addition of sodium citrate to whole milk and skim-milk diets, fed to calves from 11 days of age, had no effect on fecal consistency. It has been suggested (103) that milk curds of a cottage cheese consistency may be difficult for the young calf to digest. Sheehy (93) found that young calves which had died from digestive disorders had their stomachs and duodenums congested with abnormal amounts of milk curds. Dilution of the milk with water reduced curd formation and the accompanying digestive upsets.

Studies by Iowa workers (28, 61, 71, 95) using the palpation technique described above (31) have revealed that soft curd milks remain a shorter time in the abomasum than those of higher curd tension. Dickey et al. (28) found that 1 liter portions of skimmilk having curd tensions of 142 g. or 40 g. required approximately $9\frac{1}{2}$

and 6 3/4 hours, respectively, to be liquified and leave the abomasum. However, no significant difference was observed in the final rate of passage through the alimentary tract as determined by the appearance of a carmine marker in the feces. Mortenson et al. (61) observed that 2 liters of raw skimmilk usually left the abomasum in 12 to 18 hours whereas equivalent amounts of boiled and autoclaved milk required about 8 to 12 hours. According to Shoptaw et al. (95) soybean gruel does not form a hard coagulum and leaves the stomach more rapidly than the curd from milk. Using sodium citrate as the anti-coagulant, Owen (71) found that the citrated milk left the abomasum in less than 1 hour in comparison to about 15 hours for the untreated milk. In no case did the citrated milk form a clot, nor could diarrhea be associated with the absence of a coagulum. Undoubtedly the rate of passage of material from the abomasum is affected by the time required for liquification of the contents. However, the relationship of abomasal evacuation time to digestive upsets and digestibility in the young calf needs further investigation.

Methods of Feeding

Although beyond the scope of this review, some causes of nutritional diarrhea in young calves have been attributed to excess amounts of milk, unclean or sour milk, unclean pails and/or irregularity of milk temperature. Recently, no effect on fecal consistency was noted by Owen and Brown (72) when milk was fed at temperatures of 50 and 100° F. to calves after 14 days of age. The method of feeding calves by nipple pail or open bucket has been one of the more controversial subjects over the years. Several studies cited by Wise and Anderson (108) reported that nipple-fed calves were more thrifty and suffered from less digestive upsets because the head was elevated and the slower rate of consumption prevented milk from passing into the rumen. Milk taken by nipple has been observed (88, 108, 109) through rumen fistulas to pass directly into the abomasum while that fed from an open pail occasionally spurted into the rumen. However, the elevation of the head or occurrence of diarrhea could not be associated with the presence of milk in the rumen. Also, more recent reports (5, 48, 49) show little or no difference between the two feeding methods on rate of growth or incidence of diarrhea.

Possible Mechanisms Associated With Nutritionally Induced Diarrhea

The laxative effects of various dietary constituents have been reported; however, the mode of action of these constituents is apparently diverse and often obscure. Many studies have been conducted to explain the etiology of lactose and mineral laxation. Some of the possible means by which these and other dietary constituents may influence fecal consistency include the following:

A. Direct irritation of the intestinal musculature, thereby causing stronger or more frequent contractions that increase the rate of passage of material through the bowel. Such an effect has been attributed to the excess acid produced when lactose was fed (32). Inflammatory irritation also has been suggested as the mode of action of saline cathartics. According to Milks (58) the soaps of saponified fats may be irritating enough to cause increased peristalsis, or in the presence of excess fats or oils act as milk laxatives. On the other hand, Owen et al. (73) has suggested that butterfat may reduce the cathartic action of an irritant by providing a protective coating to the mucosa.

B. Development of a hydragogue action which produces distention of the intestinal tract and a watery purgation. Magnesium sulfate, sodium sulfate or phosphate and other saline cathartics which undergo only slight absorption are effective in producing increased fluid retention in the intestines through osmosis (13). Distention of the intestinal tract by the large liquid content stimulates the intestines to contraction and flushes the tract. A hydragogue effect also has been suggested as the mechanism of lactose-induced diarrhea (32). The effect of fat in reducing mineral laxation may be related to the conjugation of the fatty acids with the minerals, reducing osmotic pressure by a decrease in molecular entities or increasing mineral utilization (73). Fat may act in a similar manner to reduce laxation provoked by other dietary constituents.

C. Alteration of the intestinal flora in the lower portion of the digestive tract (32). The slow digestion or absorption of nutrients may allow the passage of undigested material into the large intestine where conditions are favorable for fermentation and bacterial proliferation (9). According to Blaxter and Wood (19) there follows two possible sequels to the inception of diarrhea: (a) direct tissue invasion through increased numbers of coliform organisms and; (b) toxic, hydragogue, or irritating effects of the products of bacterial metabolism. On the other hand, the aciduric flora characterized by feeding lactose may in certain cases (33, 34, 107) reduce undesirable fermentation and laxation.

D. Increased intestinal muscular activity following the absorption of certain nutrients which may act from the blood on the nerve supply of the intestine. Such a theory has been proposed for lactose because small amounts of the disaccharide are absorbed into the blood stream without being hydrolyzed (32). The laxative action has been associated with the lactose molecule and not its hydrolysis products, glucose and galactose.

E. Increased secretion and/or excretion of bile which is recognized as possessing a laxative action (96). Solutions of magnesium sulfate relax the tonus of the common bile duct sphincter which usually leads to evacuation of the gall bladder. The greenish appearance of feces observed during diarrhea may be the result of the excretion of large amounts of bile (100). Fat may reduce the laxative effect of bile by complexing of fatty acids with bile acids (73).

EXPERIMENTAL PROCEDURE

Plan of Experiment

Thirty-two male Holstein calves, three days of age, were used to study the dietary effects of fat and/or minerals on fecal consistency. A randomized blocks design with a 2 x 2 factorial arrangement of treatments was employed. Sixteen calves (Block A) were used for radiograph studies and later sacrificed, while the other 16 calves (Block B) were maintained on the experimental rations until 24 days of age. The calves within each block were assigned at random to the following treatment groups: 1, Basal skimmilk diet; 2, Basal diet plus fat; 3, Basal diet plus minerals; 4, Basal diet plus minerals and fat. Animal tallow[1] was employed as the source of fat because it had previously been used successfully in milk replacer rations and was representative of the type of ingredients used in the formulation of milk replacers. The mineral supplement[2] was selected because of the diarrheic effects observed by Owen _et al_. (36) when this mixture, which closely simulates whey ash, was added to the milk diets of young calves.

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[1] Prime tallow, titer 39.6° C. Purchased from Wilson and Co., Oklahoma City, Oklahoma.

[2] Mineral supplement contained 450 g. $CaHPO_4 \cdot 2H_2O$, 360 g. K_2HPO_4, 175 g. $MgSO_4$, and 390 g. NaCl.

The calves of Block A were radiographed at specified times to determine the amount of time for abomasal evacuation and passage of the contents through the intestinal tract. Also, these calves were sacrificed for digestive studies after 14 days on the experimental diets. The other 16 calves, Block B, received the experimental diets for 21 days to provide additional time for observations and possible adaptation to the high-mineral diets. In addition, these calves were fed carmine at specified times to determine the time required for the marker to pass through the alimentary tract and to appear in the feces.

Feeding and Management of Calves

The calves were obtained at one and two days of age from selected dairy farms within about a 40-mile radius of the University. They were transported in a covered truck to the experimental barn and placed in individual pens fitted with expanded-metal-screen bottoms two inches above the floor. The barn was cooled and heated by units thermostatically controlled so that the minimum temperature was not lower than about 60° F. and the maximum temperature not higher than about 85° F.

Each calf received colostrum until one and one-half days of age. On the evening of the second day all calves were fed homogenized milk at the rate of 8% body weight. Beginning at three days of age, the experimental diets were administered via nipple pail twice daily at 12-hour intervals. The milk was warmed to about 40° C. before feeding. Each calf received 6.3 g. of a mixture of antibiotic and vitamins (Appendix Table VIII) along with the milk at the morning feeding each day. Calves receiving the high mineral diets were fed the extra minerals twice daily at the rate of 2.1% of the milk consumed. The calves were fed the experimental diets at the rate of 8% of their initial body weights to minimize the possibility of inducing diarrhea by over-feeding. When diarrhea occurred there was no reduction or modification of the diet. A constant allowance of the diets was fed throughout the experiment so that quantitative changes in liquid intake would not confound the interpretation of the results.

Animals that were not used for the radiograph studies were fed 100 mg. of carmine per pound of milk on the 2nd, 8th, and 14th days of the experiment to determine the length of time required for the diets to pass through the digestive tract. The carmine was administered by mixing it with the milk immediately before feeding.

Observations were made at approximately 3 A.M., 6 A.M., 9 A.M., 2 P.M., 5 P.M., 8 P.M., 10 P.M., and at various intervals between these times on the incidence and severity of diarrhea. A record was thus made of the frequency of defecation by each calf and of the color and consistency of the feces. Fecal consistency was rated on an arbitrary scale of one through four denoting: 1, normal; 2, very soft; 3, semi-fluid and 4, extremely fluid feces. Animals that did not defecate during a 24-hr. period were given the same rating as an animal having one defecation of feces with normal consistency. A daily fecal-index value for each calf was obtained by considering the number of defecations and the average fecal consistency as shown in Table II. For example, a fecal index value of 24 was obtained from the table if a calf had three defecations with an average consistency rating of four.

TABLE II

INDICES USED IN MAKING DAILY FECAL EVALUATIONS ON CALVES

Number of defecations	Severity rating[a]			
	1	2	4	8
0	1	1	1	1
1	1	2	4	8
2	2	4	8	16
3	3	6	12	24
4	4	8	16	32
5	5	10	20	40
6	6	12	24	48

[a] The severity ratings were obtained by assigning progressive values to the original fecal consistency ratings. Thus, the original consistency ratings of 1, 2, 3, and 4 were assigned severity ratings of 1, 2, 4, and 8.

Body weights and temperatures were obtained each evening prior to feeding. Diarrhea was assumed to be of nutritional origin if the daily rectal temperature did not consistently remain above 103.5° F. A blood sample was taken from each calf on the morning of the first day of the experiment and at 4-day intervals thereafter, except on Sunday or on a day when radiographs were made. In the latter cases, the samples were taken either the day before or the day after the regularly scheduled time. Hematocrit values were obtained on the fresh blood for the purpose of determining whether hemoconcentration had occurred to an extent that would indicate dehydration of the animal.

Preparation of Experimental Rations

The basal diet was reconstituted dried skimmilk[3] containing 10% total solids. The filled milks were prepared by adding the animal tallow to the basal skimmilk ration at the time of reconstituting to provide a product containing 3% fat. Each filled milk was heated to approximately 70° C. and passed twice through a homogenizer at 2000 lb. p.s.i. All rations were prepared and pasteurized in 10-gallon milk cans. To each can of milk 2.1 g. of an antiobiotic-trace mineral mixture (Appendix Table IX) and 14.5 g.

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[3] High-heat roller process. Purchased from Goldspot Dairy, Inc., Stillwater, Oklahoma

of choline chloride were added. The diets were prepared every 7 to 10 days and stored at 10° C. Samples of milk were taken during storage and checked for bacterial count. The high-mineral diets were prepared by mixing the minerals into the milk at the time of each feeding.

Radiograph technique

A series of radiographs was taken of each of 16 calves on the 2nd and 9th days of the experiment. The animals were moved to the veterinary clinic on the morning that each series of radiographs was taken. Barium sulfate[4] was administered at the rate of 1 oz. per pound of the usual diet. The barium was blended with a small portion of the milk for 10 sec. in a Waring blender and then stirred into the remaining amount of the diet by hand. A survey radiograph was taken of each calf just before feeding the contrast media. The barium meal was then administered via nipple pail and a series of radiographs was taken according to the following schedule: immediately, 30 min., 3 hr., 9 hr., 12 hr., and 24 hr. after feeding the contrast media. During the radiograph study the calves received their regular amount of diet immediately after the radiographs were taken at 12 and 24 hr. Additional radiographs were taken after 24 hr. if contrast media was still present in the abomasum or area of the small intestines.

[4] Barotrast. This product was supplied by the Barnes-Hind Barium Products Co., Sunnyvale, California.

Radiographs were taken of the calves in a standing position using a portable X-ray machine as shown in Plate I. In order to observe as much of the gastrointestinal tract as possible the calf was carefully positioned in front of the cassette with the exact position depending upon the extent to which the contrast media was presumed to have passed through the digestive tract. A special cassette stand was constructed to maintain a uniform distance between the cassette and the X-ray tube when the machine was moved into position. This arrangement enabled the machine to be set up quickly and also prevented accidental movement of the cassette stand or machine during the positioning of the calf.

Digestion Study

The 16 calves which had been used for the radiograph studies were sacrificed at 6 hours $\pm$ 10 minutes after the morning feeding on the 15th day of the experiment. In preliminary radiograph studies it appeared that the diet was well dispersed through the small intestines within this time. In addition, it seemed desirable to sacrifice the animals before excessive loss of the tract contents occurred in the calves having diarrhea.

The calves were killed by electrocution and the jugular veins were immediately severed. Within a few minutes after death the abdomen was opened and the right side of the rib cage was removed. The intestinal tract was immediately ligated with string

PLATE I

at about 30 diverse points, including the cardia, reticulo-omasal orifice and the area of the ileo-caecal orifice, to prevent excessive movement and mixing of the tract contents. The entire intestinal tract was laid out and divided into sections for sampling purposes as follows: abomasum, rumen, anterior one-half of the small intestine, posterior one-half of the small intestine, anterior one-half of the large intestine, and the posterior one-half of the large intestine. The contents of each of the four intestinal segments were obtained by stripping the intestine twice between the thumb and forefinger forcing the material into beakers. In removing the materials from the various sections considerable care was taken to keep blood, body fluids and other foreign constituents from mixing with the tract contents. Each sample was weighed immediately to the nearest one-tenth of a gram and the pH was determined. Representative samples of the contents of each section were taken and stored at -20° C.

The methods used in determining the proximate analysis of the samples were essentially those recommended by the Association of Official Agricultural Chemists (116). Because of the characteristics of the liquid samples, certain specific techniques were developed to analyze them. It was found that drying the samples at 100° C. was unsatisfactory since carmelization of the sugars occurred. To reduce this effect the dry matter was determined by drying a 10-

ml. sample in a vacuum oven (21 inches of vacuum) at 60° C. for 16 hours. The same dried sample was then ashed at $500-600^{\circ}$ C.

For the fat analysis, about 5 g. of sample was weighed into a glass tube containing absorbent cotton. The tube was dried in the vacuum oven for 24 hours, re-weighed and extracted with ethyl ether overnight in a Kmoor extraction apparatus. The tube was then dried for 5 hours and the difference in the dry weights was taken as the weight of fat. For the protein determination the material was weighed into a beaker and then washed into the Kjeldahl flask with distilled water. The percentage of nitrogen thus obtained was multiplied by the factor 6.25 to determine the amount of protein in the sample.

RESULTS AND DISCUSSION

Considering the nature of the experimental diets used in this study, the general performance of the calves may be considered satisfactory. It was necessary, however, to replace two calves in Group A-4 (Block A, Treatment 4) and one calf in Group B-2 (Block B, Treatment 2) during the course of the experiment.

The latter calf was removed from the experiment after exhibiting diarrhea accompanied by a high temperature, indicating presence of infection. Calves No. 19 and 41 in Group A-4 died on the 13th and 14th days of the experiment, respectively. An autopsy of both animals showed that they had an infection; however, no evidence of infection was observed in either calf during the second radiograph study. Since the radiography study represented only one specific part of the experiment, the radiographic data obtained on calves No. 19 and 41 were used for that phase of the study. All other data on these calves were discarded and two new calves, No. 8 and 42, were placed in Group A-4 to obtain the fecal and slaughter data. On the 2nd and 9th days of the experiment both of these calves were fed barium sulfate to simulate the radiographic conditions, although they were not radiographed.

Apart from the exceptions noted above, all the calves continued to consume the prescribed amounts of the experimental diets even though relatively severe non-infectious diarrhea was evident in some cases. This was reflected in no changes in hematocrit values of sufficient magnitude to indicate dehydration of an animal (Appendix Table XII). Also, there were no appreciable changes in body weights of the calves during the course of the experiment. Since the experimental rations comprised the sole diet of the calves and the amount was limited to 8% of the initial body weight, it is doubtful whether the energy intake was high enough to permit any appreciable growth even if no diarrhea had been present.

The average daily fecal indices for each group of four calves receiving the experimental diets for 14 and 21 days are listed in Appendix Tables X and XI, respectively. These data, which are also presented graphically in Figures 1 and 2, reveal marked differences in the severity of diarrhea in calves receiving the various experimental diets. Fat appeared to be effective in reducing laxation in calves receiving the skim-fat diets and tended to delay the appearance of diarrhea in calves when added to a high-mineral diet. However, the severity of diarrhea in calves receiving the latter diet was not reduced by the addition of fat. The low incidence and severity of diarrhea in the calves in Group B-4 after 14 days indicate a costive action for fat; however, the response of this group during this period may have been partly due to changes

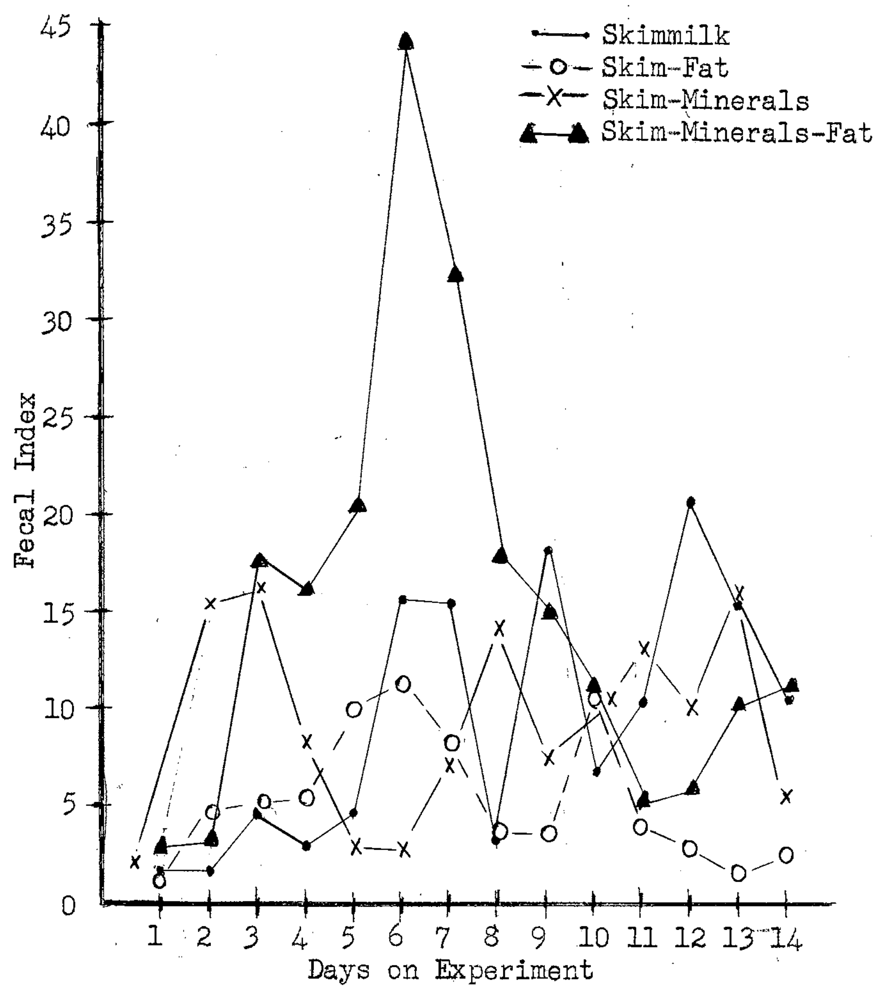


Figure 1. Average Daily Fecal Indices For Calves Fed Experimental Diets For 14 Days

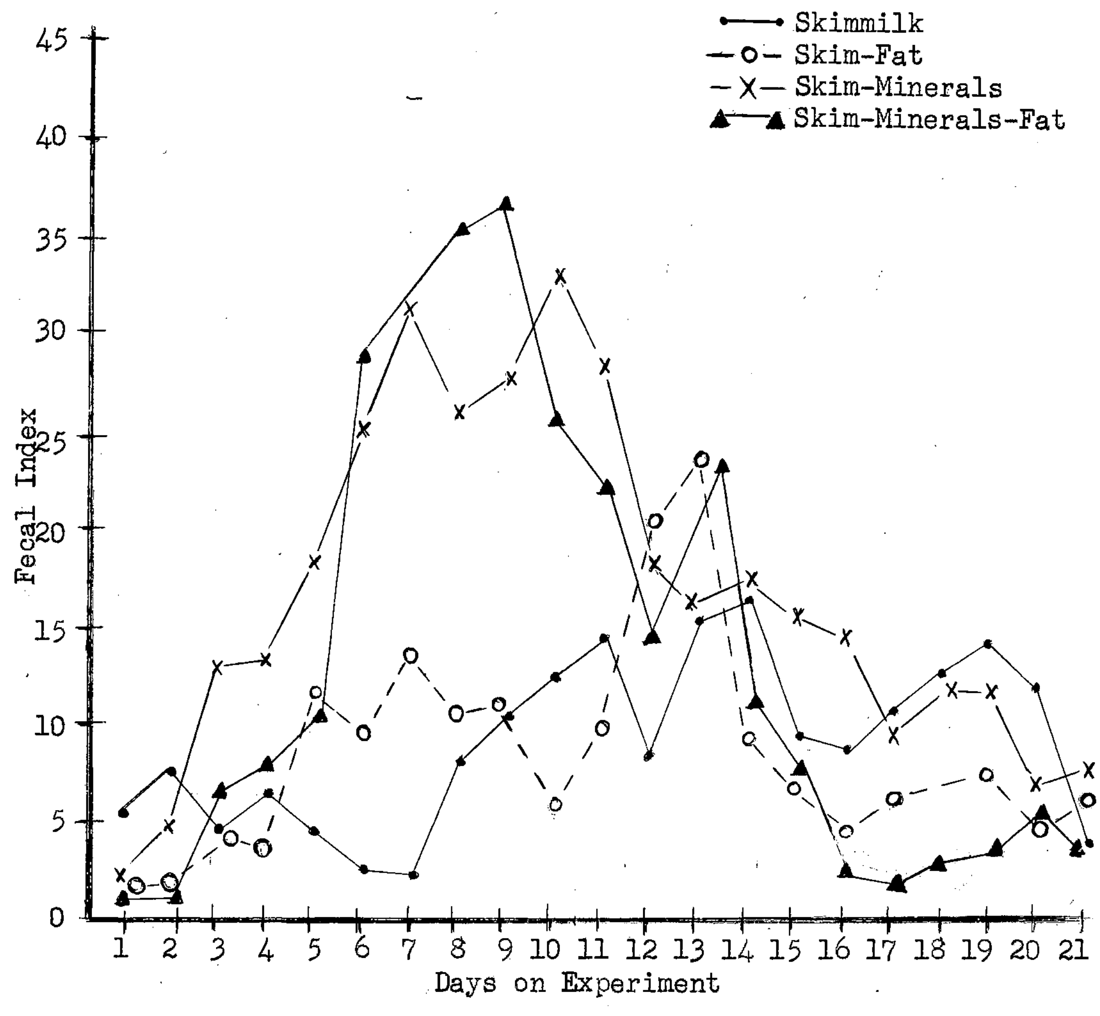


Figure 2. Average Daily Fecal Indices For Calves Fed Experimental Diets For 21 Days

in the calves as they became older.

The lack of a costive action of fat in the present experiment is in contrast to work reported by Owen et al. (73) who found that butterfat significantly reduced the laxation of milk diets containing additional minerals. However, the calves used by the latter workers were 11 days of age when feeding of the experimental diets was begun. The costive effect of fat may depend on the type of fat employed in the diet since other workers (24, 29, 30) observed a much lower incidence of diarrhea in calves fed butterfat or butter oil-filled milk diets than in calves receiving lard, tallow or vegetable oils.

Adaptation to the diets causing the more severe diarrhea is indicated in Figures 1 and 2 by a decline in the fecal-index values. Calves in Group B-4 had the highest fecal indices of all the groups from 7 to 9 days but the lowest group values from 16 to 21 days. Owen et al. (73) also observed that the continued feeding of diarrheic diets to young calves was generally accompanied by a reduction in the severity of the diarrhea.

Analyses of variance of the fecal-index values using the I B M 650 electronic computer revealed highly significant differences among periods (days), diets and the interaction of periods and diets at the 0.5% level of probability (Tables III and IV).

TABLE III

ANALYSIS OF VARIANCE ON FECAL INDICES OF CALVES RECEIVING EXPERIMENTAL DIETS FOR 14 DAYS.

Source of Variation[a]	Degrees of Freedom	Mean Square	F
Periods (P)	13	263.77	2.44[b]
Diets (D)	3	1137.66	10.51[b]
P x D	39	204.72	1.89[b]
Error	168	108.27	

[a] Interactions not approaching statistical significance omitted from table.

[b] $P < 0.005$.

TABLE IV

ANALYSIS OF VARIANCE ON FECAL INDICES OF CALVES RECEIVING EXPERIMENTAL DIETS FOR 21 DAYS.

Source of Variation[a]	Degrees of Freedom	Mean Square	F
Periods (P)	20	640.5	5.46[b]
Diets (D)	3	1398.7	11.91[b]
P x D	60	194.7	1.66[b]
Error	252	117.4	

[a] Interactions not approaching statistical significance omitted from table.

[b] $P < 0.005$.

A high level of minerals seems to be a definite factor in the cause of much of the diarrhea which occurred in this study. It is noted, however, that the most diarrheic diet contained both minerals and fat since the calves receiving the skimmilk plus minerals in Group A-3 had an average fecal-index value similar to calves receiving skimmilk in Groups A-1 and B-1 (Table V).

TABLE V

AVERAGE FECAL INDICES OF CALVES FED THE EXPERIMENTAL DIETS FOR 14 AND 21 DAYS.

	Diets			
	1	2	3	4
Group A	9.50	5.29	9.43	16.18
Group B	9.08	8.19	16.17	14.04

The radiograph data obtained on the passage of the experimental diets from the abomasum are summarized in Table VI. There does not appear to be any definite relationship between the composition of the experimental diets and the rate of their disappearance from the abomasum. Furthermore, the consistency of the feces, on the day the radiographs were taken, does not appear to be associated with the length of time that the experimental diets remained in the abomasum. Thus, the diarrheic effect of the high-mineral diets used in this experiment can not be attributed to an alteration in abomasal-emptying time.

No explanation can be given for the extended period of time the barium meal remained in a curd-like form in the abomasum of Calf No. 6

TABLE VI

PASSAGE OF BARIUM TEST DIET THROUGH THE ABOMASUM OF DAIRY CALVES AS DETERMINED BY RADIOGRAPHS TAKEN AT SPECIFIED INTERVALS AFTER FEEDING.[a]

			4 days of age		11 days of age	
Group[b]	Calf No.	Amount of test diet	Fecal index[c]	Time last observed in abomasum	Fecal index[c]	Time last observed in abomasum
		(lb.)		(hr.)		(hr.)
1	2	3.2	1	3[d]	3	12
	10	3.4	1	3	28	3
	13	3.4	3	12	32	12
	18	3.4	1	12	10	3
2	1	3.8	1	12	3	12
	6	3.4	8	97[e]	2	12
	11	3.6	6	12	3	3
	12	3.2	4	24	6	3
3	4	3.5	18	12	8	3
	9	3.0	12	24	8	9
	14	3.2	24	12	8	12
	17	3.6	20	9	3	12
4	3	3.7	1	3	6	3
	15	3.8	14	33	12	12
	19[f]	2.9	1	33	40	12
	41[f]	3.9	2	9	16	12

[a] The schedule of radiographs was as follows: Survey, immediate, 30 min., 3 hr., 9 hr., 12 hr., 24 hr. Additional radiographs were taken if material was observed in the abomasum 24 hours after feeding.

[b] Group 1: Skim — Group 3: Skim and Minerals
Group 2: Skim and Fat — Group 4: Skim, Fat and Minerals

[c] Index on day that radiograph was taken.

[d] No 9-hr. radiograph taken.

[e] Calf was massaged before material left abomasum.

[f] Calves used for data on radiograph only.

at 4 days of age. After 81 hr., this calf was turned on its back and the abdomen was massaged. A radiograph taken after this manipulation showed the material to be scattered throughout the abomasum. This prolonged retention of the diet was not observed at 11 days of age.

The average time required for the experimental diets to be liquified and leave the abomasum was much less for the calves at 11 days of age than it was at 4 days of age. Omitting the data for Calf No. 6, the average time required for emptying of the stomach was 14.2 $\pm$ 9.8 hr. (standard deviation) in the calves at 4 days of age as compared to 8.2 $\pm$ 4.4 hr. at 11 days of age. This decrease in abomasal-emptying time may well be the result of increased development of the gastric secretion and enzyme functions as the calves grow older.

The curd tension of the experimental diets, as determined by the rennet coagulation test, was found to range from 0 to 5 g. Regardless of these low values the experimental diets were observed to remain in the abomasum for a considerable time. Also, curds were found in the stomachs of calves sacrificed at 17 days of age. The average time required for abomasal evacuation as observed by use of radiographs is in general agreement with that reported by other workers (37, 39) using a palpation technique.

The average length of time required for the barium test-diets to traverse the digestive tract to the rectum was about 9 hr. for the calves at both 4 and 11 days of age. The time necessary for the carmine to pass through the tract and appear in the feces was at least 24 hr. in many cases. An average of 27.8 hr. was required for the carmine to appear in the feces when the fecal-index values were less than 10, but an average of only 11.2 hr. was necessary for passage of the carmine when the index values were above 10. The latter transit time is similar to that observed in the radiograph studies and may possibly be explained on the basis of more frequent defecations when the calves exhibited diarrhea. Owen (71) observed that similar diets containing carmine had passed into the terminal portion of the large intestine in calves sacrificed 14 hr. after feeding. This suggests that determining the time of passage of milk diets in young calves by the use of carmine is not very reliable unless one manually stimulates the animals to defecate at regular intervals as did Owen and Brown (72). Carmine has been reported to increase gastric emptying time and delay the movement of material through the intestines, while barium sulfate slowed gastrointestinal motility in children (56). Although, barium sulfate often has a costive effect there was no evidence of constipation or inspissation following the use of the micronized barium sulfate, Barotrast. Whether or not the carmine or barium sulfate affected rate of passage or digestion of nutrients by calves in this study is not known; however, the possibility of such an effect should be recognized. At any rate the use of the radiograph technique permitted digestive studies to be made in very young calves. Thus this method is beleved to be more practical than one involving palpation via rumen fistulas. Furthermore it is doubtful whether this technique interfers with the digestive process in the young calf any more than the presence of a rumen fistula.

Calves exhibiting diarrhea were often observed to have considerable amounts of fluid in the large intestine causing marked distention. The shape of the abomasum appeared to be more irregular at 4 days of age than at 11 days. In one calf, at both 4 and 11 days of age, the abomasum was nearly turned around with much of the small intestine located ventrally and toward the front of the stomach. Evidence of colitis was seen in several animals at 11 days of age, but the condition could not be related to any specific diet. Also, four calves were observed to have an umbilical hernia.

A series of radiographs of Calf No. 11, at 11 days of age, showing the passage of the diet through the gastrointestinal tract are presented in Plates II through VIII. The survey radiograph (Plate II) was taken about 10 min. before the contrast media was fed. A total of 99 g. of "Barotrast" was administered to the calf in 3.6 lb. of the skim-fat diet. A general outline of the abomasum, with a fluid level in the pyloric portion, may be seen in the film (Plate III) taken immediately after feeding the barium meal. In the film taken 30 min. after feeding (Plate IV), the abomasum is more rounded and some of the contrast media is seen in the small intestine. After 3 hours the contrast media is dispersed throughout the small intestine (Plate V). In the 9-hr. film (Plate VI) almost all of the contrast media has left the abomasum and is mainly in the large intestine. The contrast media is in the terminal portion of the large intestine in the 12-hr. film (Plate VII) and contractions of the large intestine can be seen. The 24-hr. radiograph (Plate VIII) is similar to the preceding film, except more barium is present in the rectum.

PLATE II

SURVEY RADIOGRAPH

PLATE II

PLATE III

IMMEDIATE RADIOGRAPH

a, Abomasum

PLATE III

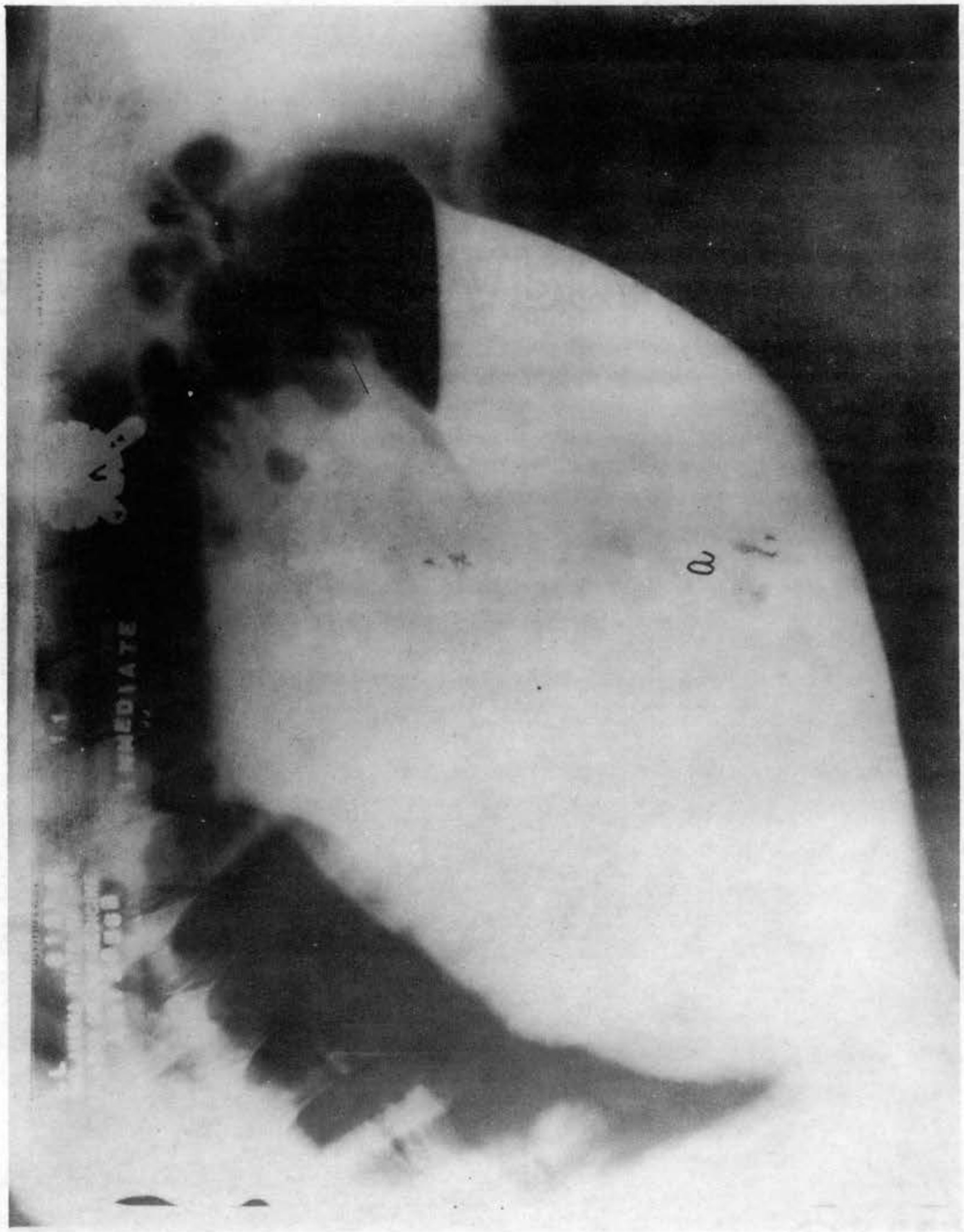


PLATE IV

30-MINUTE RADIOGRAPH

a, Abomasum

i, Small Intestine

PLATE IV

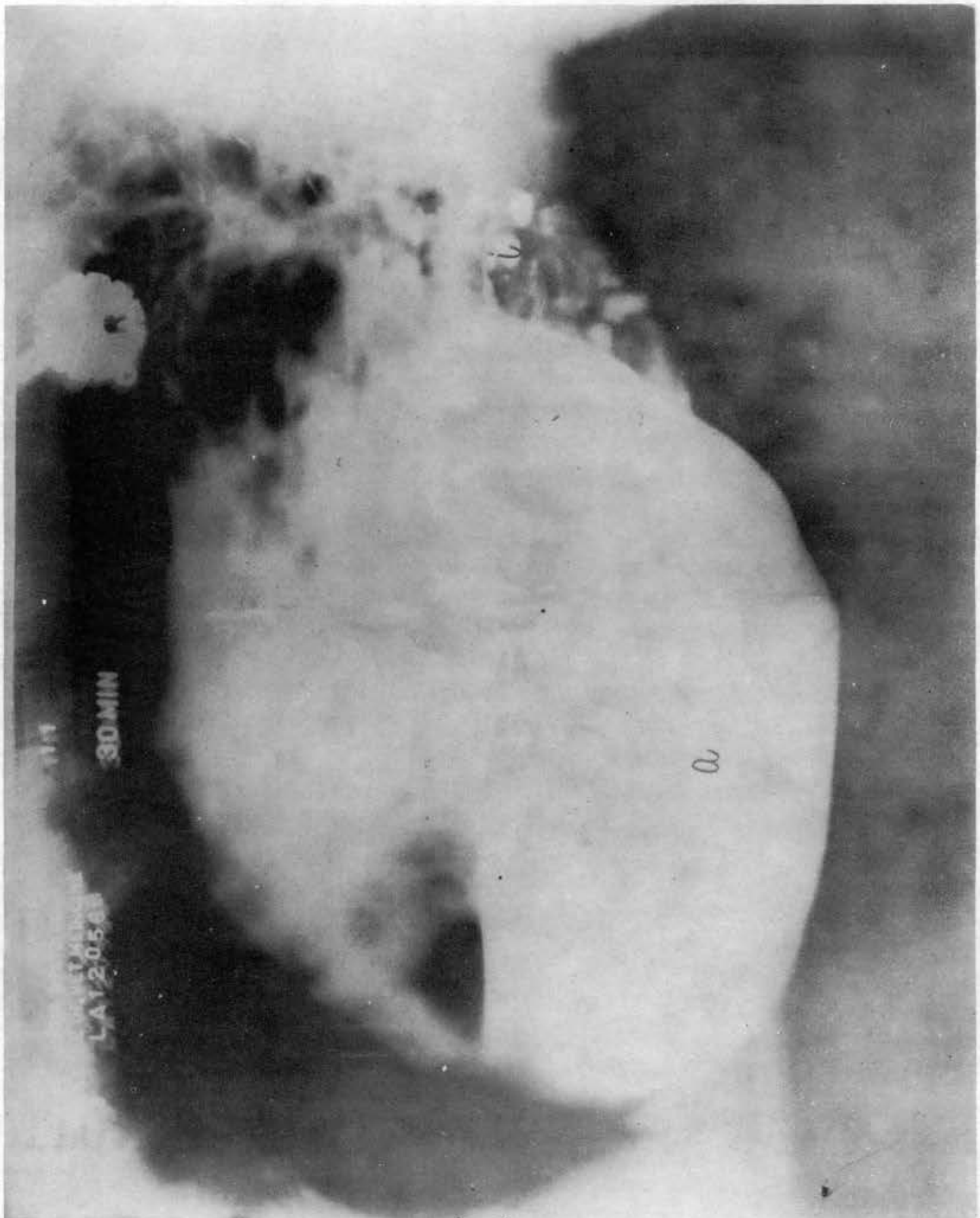


PLATE V

3-HOUR RADIOGRAPH

a, Abomasum

i, k, Small Intestine

PLATE V

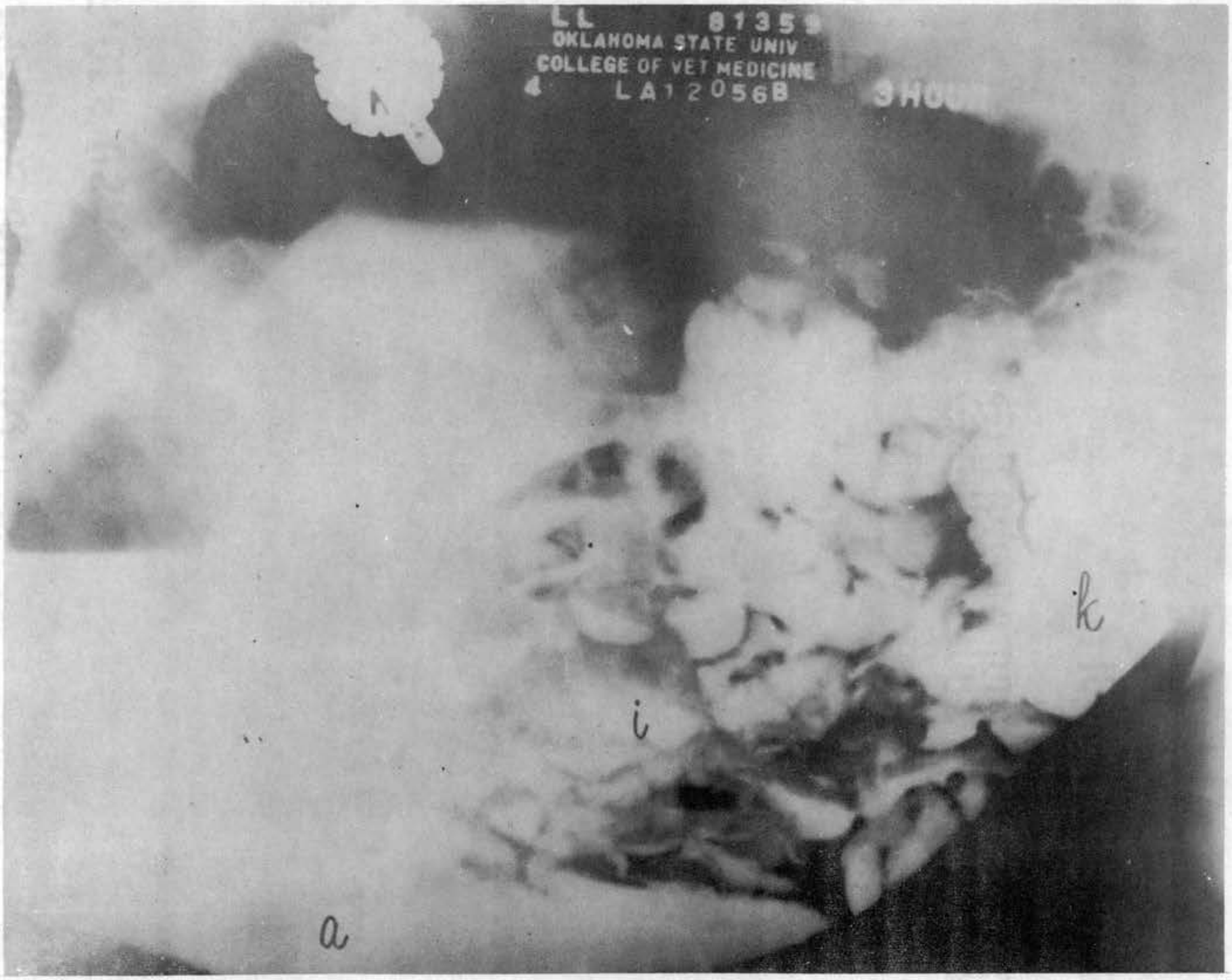


PLATE VI

9-HOUR RADIOGRAPH

k, Small Intestine

g, Large Intestine

y, Rectum

PLATE VI

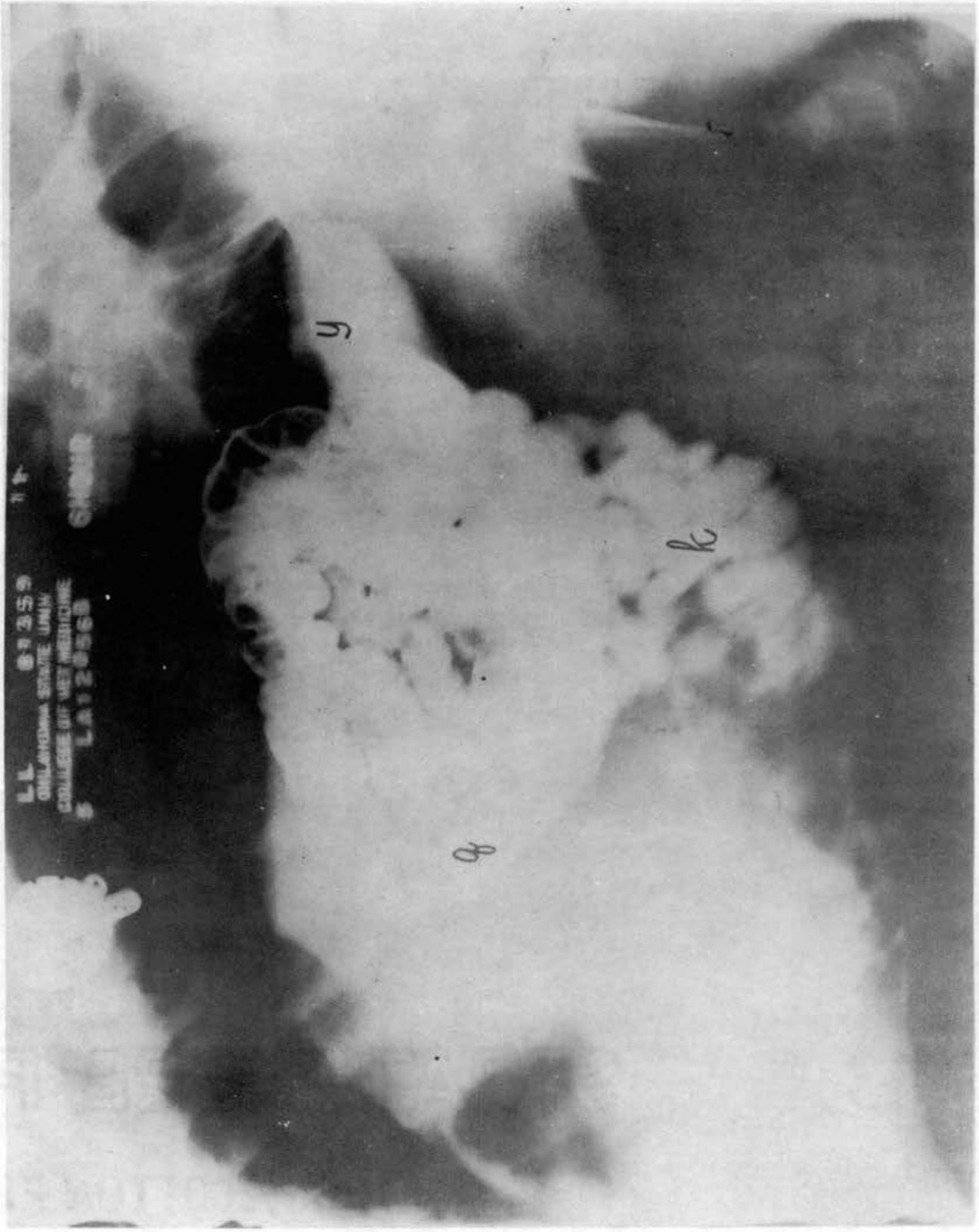


PLATE VII

12-HOUR RADIOGRAPH

q, Large Intestine

PLATE VII

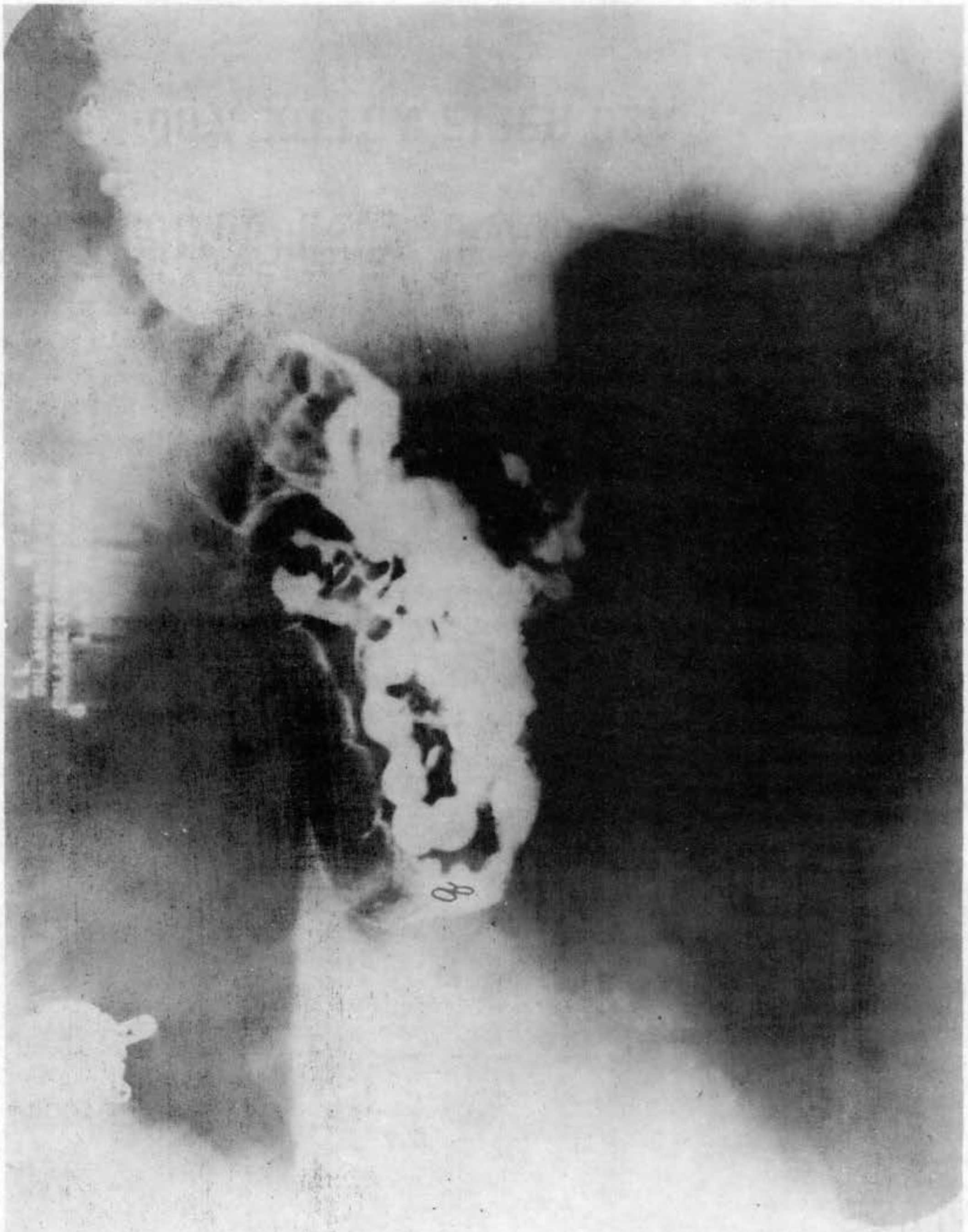


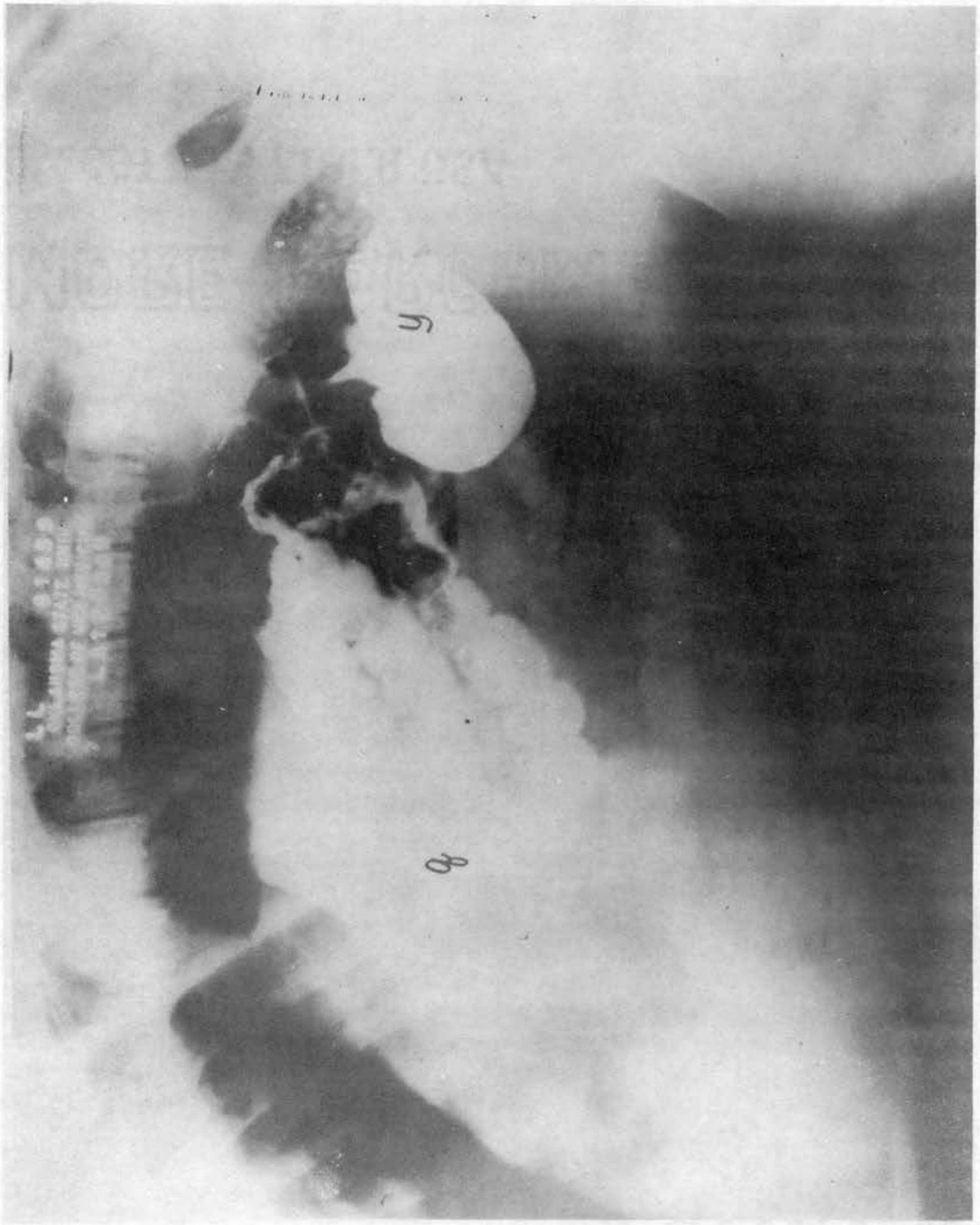
PLATE VIII

24-HOUR RADIOGRAPH

X, Large Intestine

Y, Rectum

PLATE VIII



The average fecal index values for calves in Groups 1,2,3 and 4 of Block A for the 24-hr. period before sacrifice were 11, 3, 5 and 12, respectively. Calves No. 10 and 13 in Group A-1 were the only ones that exhibited fluid feces during the 24-hr. period while all calves in Group A-4 had very soft feces. The total weights of the contents in various segments of the digestive tract of these calves sacrificed at 17 days of age are presented in Appendix Table XV. The amount of material in the digestive tract was approximately the same for each group except for Group A-1 where a smaller amount was recovered. However, the difference did not approach statistical significance (P, .05). Although two calves in Group A-1 had diarrhea, the amount of material in the alimentary tract could not be related to the fecal consistency due to wide variation within the group. An analysis of variance revealed that the differences among segments were statistically significant at the 0.5% level of probability; however, within all of the segments except the rumen and abomasum the weights of the contents were highly variable (Appendix Table XV).

The fluid in the rumen often had an offensive, sour odor and contained small amounts of hair and particles of wood or straw. Four calves were observed to have a few small granules of curd in the rumen fluid. Calves in Groups A-1 and A-3, receiving no fat in the diet, had several curds about 1 to 1 $^1/_2$ sq. in. in the abomasum, whereas only small granular curds about one-fourth of an inch or less were observed in the abomasal contents in Groups A-2 and A-4. Almost all calves had some granules of curd in the small intestine but only a few calves had any curd in the large intestine and this could not be associated with the diet or fecal consistency.

An analysis of variance of the pH of the digestive tract contents (Appendix Table XXII) revealed statistically significant differences among segments at the 0.5% level of probability. However, these differences were largely due to the normal low pH value of the abomasal contents (Appendix Table XIV). There were no significant differences in pH values among diets nor any interaction of segments and diets.

The percentage and average amounts of dry matter in the various segments of the digestive tract are presented in Appendix Tables XVI and XXI, respectively. In relation to the amount of diet fed, Group A-2 had the largest amount of dry matter in the small intestine, suggesting a slower rate of passage from this segment. The greater amounts of dry matter in the large intestines of calves in Groups A-1, A-3 and A-4 indicates that the diets passed through the digestive tract more rapidly; however, the amount of dry matter in the various segments could not be related to the fecal consistency. Possibly some of the material remaining in the large intestines is associated with a previous feeding. The smaller amount of dry matter in the abomasum in Group A-4 suggests a more rapid emptying of the stomach, but the difference was not statistically significant ($P > .05$). This is in agreement with the observations made during the radiograph studies. Also, the rapid disappearance of dry matter from the abomasum in Group A-4 could not be related to fecal consistency.

The average percentages and total amounts of protein, fat, carbohydrate, and ash are presented in Table VII and Appendix Table XXI. In comparison to other nutrients in various parts of the digestive

TABLE VII

COMPOSITION OF DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.[a]

Group[b]	Rumen %	Abomasum %	Small Intestine Seg.I %	Small Intestine Seg.II %	Large Intestine Seg.I %	Large Intestine Seg.II %
			(Protein)			
1	40.01	58.21	55.78	46.75	49.05	59.91
2	41.27	33.20	36.84	34.98	30.03	33.61
3	38.95	57.71	58.58	50.17	39.43	44.74
4	38.71	33.88	50.02	51.30	38.33	43.28
			(Fat)			
1	13.12	1.24	4.64	1.15	0.82	3.57
2	6.36	33.11	15.57	8.87	6.56	6.20
3	3.05	0.20	4.70	1.80	2.57	2.89
4	5.12	25.85	13.15	9.28	11.14	7.93
			(N F E)			
1	4.07	25.57	26.20	36.45	32.40	19.87
2	16.33	19.90	27.56	34.96	39.08	32.55
3	29.28	19.26	48.25	26.22	25.92	17.20
4	11.02	26.24	23.32	20.57	20.90	21.71
			(Ash)			
1	47.88	6.83	10.04	15.91	14.89	15.92
2	43.21	9.24	9.79	13.08	12.59	13.09
3	59.50	16.81	16.11	21.78	32.08	35.22
4	45.11	14.03	13.35	19.98	29.64	27.08

[a] All values expressed on a moisture-free basis.

[b] Group 1: Skim Group 3: Skim and Minerals
Group 2: Skim and Fat Group 4: Skim, Fat and Minerals

tract protein seemed to disappear more slowly and a greater amount was recovered from the large intestine. In relation to the amount of dry matter Group A-2 appears to have made better utilization of the protein as it passed through the digestive tract.

The average amount of fat in the dry matter of the digestive tract contents was similar for Groups A-2 and A-4 receiving the lard-filled diets except that Group A-4 had a larger amount of lipid material in the upper half of the large intestine. However, the fat was well utilized by both groups as evidenced by the low lipid values in the lower portion of the large intestine.

Only small differences were found in the amount of nitrogen-free extract in the various segments except in the abomasum of Group A-4 where the content was about one-half of that recovered from the other groups. It is likely that only a small percent of this was lactose since in a similar study Owen (71) was able to recover only about 1% of the carbohydrate fed.

As was expected, more ash was found in the digestive tract of calves receiving the high mineral diets in Groups A-3 and A-4. There was little difference in the amount of minerals fed and that recovered from the digestive tracts of the two groups. The large intestine of both groups contained an average of 43% more ash on a dry matter basis than the small intestine, but the difference was not statistically significant ($P > .05$) The concentration of ash in the large intestine may be related to (a) a differental rate of passage of minerals through the digestive tract, (b) absorption from the small intestine and subsequent excretion into the large intestine, and (c) minerals remaining in the tract from previous feedings. Owen (71) also observed a greater percentage of ash in the large intestines of calves fed extra minerals; however, he found that a considerable amount of the minerals had disappeared from the gastrointestinal tract before any defecation of the test diets had occurred.

The results of the digestion studies do not show any marked differences in the contents of the digestive tracts that can be associated with fecal consistency at the time of sacrifice. The lower incidence and severity of diarrhea in Group A-3 in contrast to Group B-3, receiving the same skim-mineral diet, may have reduced possible differences between the groups in Block A. However, the possibility that differences in the digestive tract contents may have existed when the range in fecal-index values between groups was greater than at the time of sacrifice can not be discounted. Several calves exhibiting diarrhea during the radiograph studies were observed to have considerable amounts of fluid in the large intestine; whereas, little fluid or no distention was seen in the small intestine. Using a similar sampling technique, Owen (71) found no differences in the amounts or pH of digestive tract contents that could be related to the onset of diarrhea in calves having a normal fecal consistency and sacrificed 14 hr. after receiving whole milk or high lactose-mineral diets.

Although no definite costive action of animal tallow was observed, it would be desirable to investigate how other types and levels of dietary lipids affect fecal consistency in young calves. Moreover, the effects of butterfat, fractions of butterfat, melting points, storage, and methods of mixing various lipids in milk replacers warrant further study. Also, more information is needed on the relation of various lipids to soap formation and subsequent irritation of the intestinal musculature (58).

More studies are needed on the effects of various types and levels of carbohydrates and proteins on fecal consistency. Roy (84) concluded from limited studies by Rojas et al (83) and Blaster and Wood (19) that diarrhea and unthriftiness in young calves are associated with intakes of over 250 g. of lactose and/or glucose daily. Moreover, he suggested that it was unlikely that soluble carbohydrates could form the main source of energy in milk replacers since replacing 182 g. of fat in a gallon of 4% milk would require about 415 g. of sugar, a quantity that could probably not be tolerated by the young calf.

Considerable uncertainty exists concerning the necessity of curd formation in the abomasum of young calves with respect to fecal consistency (19, 34, 72). Some of the discrepancies have possibly been due to the unusual management of the calves or undesirable rations used; therefore better controlled studies on the relation of curd formation in the abomasum to the health and well being of young calves are needed.

Finally, in studying the diarrheic or costive properities of a dietary ingredient careful attention should be given to the age of the calves and the type of diets employed. Undoubtedly much of the confusion about this subject has been caused by the use of complex milk replacers and calves of an age capable of utilizing a more varied diet.

SUMMARY

Thirty-two male Holstein calves, three days of age, were used to study the dietary effects of fat and minerals on the incidence and severity of diarrhea. A randomized blocks design was employed with a 2 x 2 factorial arrangement of the following treatments: 1, Basal skimmilk diet; 2, Basal diet plus fat; 3, Basal diet plus minerals; 4, Basal diet plus minerals and fat.

Sixteen calves were radiographed on the 2nd and 9th days of the experiment to determine the amount of time required for abomasal evacuation and passage of the contents through the intestinal tract. Also, these calves were sacrificed for digestive studies after 14 days on the experimental diets. The other 16 calves received the experimental diets for 21 days to provide additional time for possible adaptation to the high-mineral diets. Carmine was fed to these calves on the 2nd, 8th, and 14th days of the experiment to determine the length of time for the diets to pass through the digestive tract. Hematocrit values were obtained every 4 days on all calves for the purpose of determing whether hemoconcentration had occurred to an extent that would indicate dehydration of the animal. A daily fecal-index value for each calf was obtained by considering the number of defecations and average fecal consistency.

Analyses of variance of the fecal-index values of calves fed the experimental diets for 14 or 21 days revealed highly significant differences among days, diets and the interaction of days and diets ($P < .005$). A high level of minerals was a definite factor in the

cause of much of the diarrhea which occurred; however, the calves receiving the skim-mineral diet for 14 days had an average fecal-index similar to calves receiving skimmilk for 14 and 21 days. Fat appeared to be effective in reducing laxation in calves when added to the basal skimmilk diet and tended to delay the appearance of diarrhea when added to diets with high levels of minerals. However, no costive action of fat was observed on the severe diarrhea associated with the latter diets. Adaptation to the continuous feeding of the diets causing the more severe diarrhea was indicated by a reduction in the severity of the diarrhea.

There were no changes in hematocrit values of sufficient magnitude to indicate dehydration of an animal. Also, there were no appreciable changes in body weights of the calves during the course of the experiment.

The radiograph studies showed no definite relationship between the composition of the experimental diets and the rate of abomasal evacuation. Furthermore, the consistency of the feces could not be related to the disappearance of the diets from the stomach. However, the time required for abomasal evacuation was less for calves at 11 days of age than it was at 4 days of age. The time required for the barium test-diets to traverse the digestive tract to the rectum was about 9 hr.; whereas, carmine often required 24 hr. or more to appear in the feces.

The average amount of material in the digestive tract of calves sacrificed at 17 days of age was approximately the same for each group, and the weight and pH of the contents in various segments of the tract could not be related to the diet or fecal consistency. Also, the dry matter, protein, carbohydrate, fat, and ash in the various segments did not appear to be related to the fecal consistency.

LITERATURE CITED

(1) ADAMS, R. S., GANDER, J. E., GULLICKSON, T. W., AND SAUTTER, J. H. Some Effects of Feeding Various Filled Milks to Dairy Calves. II. Fecal Characteristics and Digestibility Data. J. Dairy Sci., 42: 1562. 1959.

(2) ADAMS, R. S., GANDER, J. E., GULLICKSON, T. W., AND SAUTTER, J. H. Some Effects of Feeding Various Filled Milks to Dairy Calves. III. Blood Plasma Tocopherol and Vitamin A Levels, Diet Storage Effects, and Evidence of Toxicity. J. Dairy Sci., 42: 1569. 1959.

(3) ADAMS, R. S., GULLICKSON, T. W., GANDER, J. E., AND SAUTTER, J. H. Some Effects of Feeding Various Filled Milks to Dairy Calves. I. Physical Condition and Weight Gains, with Special Reference to Low-Fat Rations. J. Dairy Sci., 42: 1552. 1959.

(4) ADAMS, R. S., SAUTTER, J. H., GULLICKSON, T. W., AND GANDER, J. E. Some Effects of Feeding Various Filled Milks to Dairy Calves. IV. Necrospy Findings, Electrocardiographic Studies and Creatinuria Ratios. J. Dairy Sci., 42: 1580. 1959.

(5) ALEXANDER, G. I. Rearing Dairy Calves. Aust. Vet. J., 30: 68. 1954.

(6) ARRINGTON, L. R., AND REAVES, P. M. Studies of the Growth and Blood Composition of Dairy Calves Fed Remade Skim Milk After Three Days of Age. J. Dairy Sci., 31: 1. 1948.

(7) ASCHAFFENBURG, R., BARTLETT, S., KON, S. K., TERRY, P., THOMPSON, S. Y., AND WALKER, D. M. The Nutritive Value of Colostrum for the Calf. I. The Effect of Different Fractions of Colostrum. Brit. J. Nutrition, 3: 187. 1949.

(8) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official Methods of Analysis. 8th ed. George Banta Publ. Co., Menasha, Wisconsin. 1957.

(9) ATKINSON, R. L., KRATZER, F. H., AND STEWART, G. F. Lactose in Animal and Human Feeding: A Review. J. Dairy Sci., 40: 1114. 1957.

(10) BARKER, H. B., AND JACOBSON, N. L. Diurnal Variations in Concentrations of Fat in Blood Plasma of Calves Fed Various Types of Oils. (Abs.) J. Dairy Sci., 32: 709. 1949.

(11) BARKER, H. B., WISE, G. H., AND JACOBSON, N. L. Filled Milks for Dairy Calves. III. Comparative Value of Various Soybean Oils and Butter Oil in a Practical Dietary Regime. J. Dairy Sci., 35: 507. 1952.

(12) BATE, W., ESPE, D. AND CANNON, C. Y. Influence of Homogenization of Fat on Haircoat of Dairy Calves. J. Dairy Sci., 29: 41. 1946.

(13) BEST, C. H., AND TAYLOR, N. B. The Physiological Basis of Medical Practice. 6th ed. Williams and Wilkins Co., Baltimore. 1955.

(14) BLAXTER, K. L., AND McGILL, R. F. Muscular Dystrophy. Vet. Rev. and Annot., 1: 91. 1955.

(15) BLAXTER, K. L., AND WOOD, W. A. The Nutrition of the Young Ayrshire Calf. 1. The Endogenous Nitrogen and Basal Energy Metabolism of the Calf. Brit. J. Nutrition, 5: 11. 1951.

(16) BLAXTER, K. L., AND WOOD, W. A. The Nutrition of the Young Ayrshire Calf. 4. Some Factors Affecting the Biological Value of Protein Determined by Nitrogen Balance Methods. Brit. J. Nutrition, 5: 55. 1951.

(17) BLAXTER, K. L., AND WOOD, W. A. The Nutrition of the Young Ayrshire Calf. 5. The Nutritive Value of Whole Milk. Brit. J. Nutrition, 6: 1. 1952.

(18) BLAXTER, K. L., AND WOOD, W. A. The Nutrition for the Young Ayrshire Calf. The Biological Value of Gelatin and of Casein when Given as the Sole Source of Protein. Brit. J. Nutrition, 6: 56. 1952.

(19) BLAXTER, K. L., AND WOOD, W. A. Some Observations on the Biochemical and Physiological Events Associated with Diarrhea in Calves. Vet. Record, 65: 89. 1953.

(20) BRISSON, G. J., CUNNINGHAM, H. M., AND HASKELL, S. R. The Protein and Energy Requirements of Young Dairy Calves. Canad. J. Animal Sci., 37: 157. 1957.

(21) BROWN, D. C., READ, J., AND WILLARD, H. S. Slaked Lime as a Preventive of Scours for Whey-Fed Calves. J. Dairy Sci., 36: 319. 1953.

(22) Consolidated Products Co. (Abs.) J. Dairy Sci., 36: 318. 1953.

(23) CUNNINGHAM, H. M., AND BRISSON, G. J. The Endogenous Urinary and Metabolic Fecal Nitrogen Excretions of Newborn Dairy Calves. Canad. J. Animal Sci., 37: 152. 1957.

(24) CUNNINGHAM, H. M., AND LOOSLI, J. K. The Effect of Fat-Free Diets on Young Dairy Calves with Observations on Metabolic Fecal Fat and Digestion Coefficients for Lard and Hydrogenated Coconut Oil. J. Dairy Sci., 37: 453. 1954.

(25) DANIEL, F. K., AND HARVEY, E. H. Some Observations on the Nutritional Value of Dialyzed Whey Solids. J. Nutrition, 33: 429. 1947.

(26) De MAN, T. J. Whey Feeding Experiments on Calves and Milking Cows. Nat. Coop. Aan-en Verkoopvereniging voor de Landbouw "Centraal Bureau" Rotterdam. (Nutrition Abstr. & Revs., 20: 1052. 1951.)

(27) De MAN, T. J. Kalveropfokroef met Gehydeerde Soya-Oile. Tydschr. Diergeneesk. 76: 175. 1951. (Cited by Cunningham in Reference 24).

(28) DICKEY, H. C., ESPE, D., AND CANNON, C. Y. The Relation of the Rate of Disappearance of Milk Curd from the Calf's Abomasum to the Apparent Digestibility of its Protein. J. Dairy Sci., 22: 464. 1939.

(29) DOLLAR, A. M., AND PORTER, J. W. G. Utilization of Carbohydrates by the Young Calf. Nature, 179: 1299. 1957.

(30) DUNCAN, D. L. The Physiological Effects of Lactose. Nutrition Abstr. & Revs., 25: 309. 1955.

(31) ESPE, D. L., AND CANNON, C. Y. The Relation of the Fat Content of Milk to the Passage of the Curd from the Stomach of the Calf. J. Dairy Sci., 18: 141. 1935.

(32) FISCHER, J. E., AND SUTTON, T. S. Effects of Lactose on Gastro-Intestinal Motility: A Review. J. Dairy Sci., 32: 139. 1949.

(33) FLIPSE, R. J., HUFFMAN, C. F., DUNCAN, C. W., AND WEBSTER, H. D. Carbohydrate Utilization in the Young Calf. II. The Nutritive Value of Starch and the Effect of Lactose on the Nutritive Values of Starch and Corn Syrup in Synthetic Milk. J. Dairy Sci., 33: 557. 1950.

(34) FLIPSE, R. J., HUFFMAN, C. F., WEBSTER, H. D., AND DUNCAN, C. W. Carbohydrate Utilization in the Young Calf. I. Nutritive Value of Glucose, Corn Syrup and Lactose as Carbohydrate Sources in Synthetic Milk. J. Dairy Sci., 33: 548. 1950.

(35) FRIES, G. F., LASSITER, C. A., AND HUFFMAN, C. F. Effect of Enzyme Supplementation of Milk Replacers on the Growth of Calves. J. Dairy Sci., 41: 1081. 1958.

(36) GOLDBERGER, E. A Primer of Water, Electrolyte and Acid-Base Syndromes. Lea and Febiger. Philadelphia. 1959.

(37) GRIMES, C. W., AND GARDNER, K. E. Digestibility of Milk Fat by the Young Dairy Calf. (Abs.) J. Dairy Sci., 42: 919. 1959.

(38) GULLICKSON, T. W., FOUNTAINE, F. C., AND FITCH, J. B. Various Oils and Fats as Substitutes for Butterfat in the Ration of Young Dairy Calves. J. Dairy Sci., 25: 117, 1942.

(39) HANSEN, R. G., PHILLIPS, P. H., AND RUPEL, I. W. The Effect of Vitamin Supplements Upon Survival of New-Born Calves. J. Dairy Sci., 29: 761. 1946.

(40) HIBBS, J. W., AND KRAUSS, W. E. The Effect of Supplementary Vitamins on Blood Composition, Liver Storage, and Incidence of Scours in Calves. J. Dairy Sci., 30: 115. 1947.

(41) HUFF, J. S. Effect of an Emulsifying Agent, Glycerol-Mono-Stearate, on Blood Plasma Fat Levels and Liver Fat of Calves Fed Purified Diets. M. S. Thesis. North Carolina State College Library, Raleigh. 1950.

(42) HUFF, J. S., WAUGH, R. K. AND WISE, G. H. Effect of Glycerol-Mono-Stearate on Fat Absorption, Growth and Health of Calves. J. Dairy Sci., 34: 1056. 1951.

(43) JACOBSON, N. L., CANNON, C. Y., AND THOMAS, B. H. Filled Milks for Dairy Calves. I. Soybean Oil Versus Milk Fat. J. Dairy Sci., 32: 429. 1949.

(44) JACOBSON, N. L., ZALETEL, J. H., AND ALLEN, R. S. Effect of Various Dietary Lipids on the Blood Plasma Lipids of Dairy Calves. J. Dairy Sci., 36: 832. 1953.

(45) JARL, F. Experiments in Rearing Dairy Cattle. II. 1. Effect of Feeding Milk of Different Fat Contents to S. R. B. Calves. 2. Effect of Feeding Skim Milk Acidified with Acetic Acid to Holstein Calves. Medd. K. Lantbrukshogsk. Lantbruksforsok, 51. 1954. (Dairy Sci. Abstrs., 17: 231. 1955.)

(46) JARVIS, R. N., AND WAUGH, R. K. Cottonseed Oils in Purified and Skim Milk Diets for Calves. J. Dairy Sci., 32: 665. 1949.

(47) KASTELIC, J., BENTLEY, O. G., AND PHILLIPS, P. H. Studies on Growth and Survival of Calves Fed Semi-Synthetic Milks From Birth. J. Dairy Sci., 33: 725. 1950.

(48) KESLER, E. M., McCARTHY, R. D., AND KNODT, C. B. Nipple Versus Pail Feeding of Milk to Holstein Calves. J. Dairy Sci., 39: 542. 1956.

(49) KEYES, E. A. Feeding Dairy Calves with a Metal Nipple Bucket. Montana Agr. Expt. Sta., Bull. 507. 1955.

(50) LAMBERT, M. R., Personal Communications, February 16, 1960.

(51) LAMBERT, M. R., JACOBSON, N. L., ALLEN, R. S., AND ZALETEL, J. H. Lipid Requirements of the Young Dairy Calf. J. Dairy Sci., 36: 591. 1953.

(52) LASSITER, C. A., CHRISTIE, L. D. AND DUNCAN, C. W. Fat Studies in Dairy Calves. II. Influence of Milk Replacers Containing Various Levels of Fat on Growth Rate. Michigan Agr. Expt. Sta. Quart. Bull., 41: 321. 1958.

(53) LEIGHTON, R. E., AND REISER, R. Effects of Fat Supplements in a Simple Milk Replacer on Scours in Dairy Calves. (Abs.). J. Dairy Sci., 40: 627. 1957.

(54) LOOSLI, J. K., AND WALLACE, H. D. Influence of A P F and Aureomycin on the Growth of Dairy Calves. Proc. Soc. Expt. Biol. and Med., 75: 531. 1950.

(55) LUNDQUIST, N. S., AND PHILLIPS, P. H. Certain Dietary Factors Essential for the Growing Calf. J. Dairy Sci., 26: 1023. 1943.

(56) MACY, I. G., REYNOLDS, L., AND SOULDERS, H. J. The Effect of Carmine Upon the Gastro-Intestinal Motility of Children. Am. J. Physiol., 126: 75. 1939.

(57) McINTYRE, C. W., AND RAGSDALE, A. C. Dairy Husbandry Investigations at the Hatch Dairy Experiment Station Farm. Missouri Agr. Expt. Sta., Bull. 488. 1945.

(58) MILKS, H. J. Practical Veterinary Pharmacology, Materia Medica and Therapeutics. 6th ed. Alex Eger, Inc., Chicago. 1949.

(59) MORRISON, F. B. Feeds and Feeding. 22nd ed. Morrison Publ. Co., Ithaca, New York. 1956.

(60) MORROW, K. S. Dry Feed Systems of Raising Dairy Calves. New Hampshire Agr. Expt. Sta., Bull. 319: 31. 1940.

(61) MORTENSON, F. N., ESPE, D. L., AND CANNON, C. Y. Effect of Heating Milk on the Time which the Curds Remain in the Abomasum of Calves. J. Dairy Sci., 18: 229. 1935.

(62) MOYER, C. A. Fluid Balance. A Clinical Manual. Year Book Publishers., Inc., Chicago. 1952.

(63) MURLEY, W. R., JACOBSON, N. L., AND ALLEN, R. S. The Effect of Aureomycin Supplementation on Growth and Feed Utilization of Young Dairy Calves. J. Dairy Sci., 35: 846. 1952.

(64) MURLEY, W. R., JACOBSON, N. L., WISE, G. H., AND ALLEN, R. S. Filled Milks for Dairy Calves. II. Comparative Effects of Various Types of Soybean Oils and of Butter Oil on Health, Growth and Certain Blood Constituents. J. Dairy Sci., 32: 609. 1949.

(65) NEVENS, W. B., AND KENDALL, K. A. The Value of Supplementary Vitamin Feeding in the Rearing of Dairy Calves. J. Dairy Sci., 30: 175. 1947.

(66) NOLLER, C. H., HUFFMAN, C. F., WARD, G. M., AND DUNCAN, C. W. Dried Whey and Lactose as Supplements to a Vegetable Milk Replacer. J. Dairy Sci., 39: 992. 1956.

(67) NOLLER, C. H., WARD, G. M., McGILLIARD, A. D., HUFFMAN, C. F., AND DUNCAN, C. W. The Effect of Age of the Calf on the Availability of Nutrients in Vegetable Milk-Replacer Rations. J. Dairy Sci., 39: 1288. 1956.

(68) NORTON, C. L., EATON, H. D., LOOSLI, J. K., AND SPIELMAN, A. A. Controlled Experiments on the Value of Supplementary Vitamins for Young Dairy Calves. J. Dairy Sci., 29: 231. 1946.

(69) OKAMOTO, M., THOMAS, J. W., AND JOHNSON, T. L. Utilization of Various Carbohydrates by Young Calves. (Abs.). J. Dairy Sci., 42: 920. 1959.

(70) OLSON, W. A., AND WILLIAMS, J. B. Effect of Five Levels of Animal Fat in Calf Milk Replacers. (Abs.). J. Dairy Sci., 42: 918. 1959.

(71) OWEN, F. G. Interrelationships of Lactose, Lipids and Minerals in Nutrient Utilization by the Calf. Ph. D. thesis. Iowa State University. 1956.

(72) OWEN, F. G., AND BROWN, C. J. Interrelationships of Milk Temperature, Dilution, and Curd Formation in the Response of Calves to Whole Milk Diets. (Abs.). J. Dairy Sci., 40: 627. 1957.

(73) OWEN, F. G., JACOBSON, N. L., ALLEN. R. S., AND HOMEYER, P. G. Nutritional Factors in Calf Diarrhea. J. Dairy Sci., 41: 662. 1958.

(74) OWEN, F. G., VOELKER, H. H., JACOBSON, N. L., AND ALLEN, R. S. The Comparative Effects of Various Antibiotics and an Arsenical Upon the Growth, Health, and Certain Blood Constituents of Dairy Calves. J. Dairy Sci., 38: 891. 1955.

(75) PARRISH, D. B., BARTLEY, E. E., BURRIS, D. V., AND McINTYRE, R. T. Properties of the Colostrum of the Dairy Cow. VIII. Digestibility of Colostrum and Milk by Calves During the Early Postnatal Days of Life. J. Dairy Sci., 36: 489. 1953.

(76) PELT, M.D. van, JOHNSON, R. E., AND PLASTRIDGE, W. N. Studies on the Fecal Flora of Calves and its Relation to Calf Scours. Connecticut Agr. Expt. Sta., Bull. 306. 1953.

(77) PHILLIPS, P. H., LUNDQUIST, N. S., AND BOYER, P. D. The Effect of Vitamin A and Certain Members of the B-Complex Upon Calf Scours. J. Dairy Sci., 24: 977. 1941.

(78) PIERCE, H. B. The Absorption and Utilization of Carbohydrates. J. Nutrition, 10: 689. 1935.

(79) PRESTON, T. R. The Nutrition of Young Animals. Proc. Nutrition Soc. (Engl.), 17: 63. 1958.

(80) RAMSEY, H. A., WISE, G. H., TORE, S. B., AND WAUGH, R. K. Effects of Various Diets on the Diurnal Patterns of Blood Plasma Lipids of Dairy Calves. J. Dairy Sci., 37: 1357. 1954.

(81) RAVEN, A. M., AND ROBINSON, K. L. Studies of the Nutrition of the Young Calf. A Comparison of Starch, Lactose, and Hydrogenated Palm Oil, with Butterfat, in Milk Diets. Brit. J. Nutrition, 12: 469. 1958.

(82) RAVEN, A. M., AND ROBINSON, K. L. Studies of the Nutrition of the Young Calf. 2. The Nutritive Value of Unhydrogenated Palm Oil, Unhydrogenated Palm-Kernel Oil, and Butterfat, as Additions to a Milk Diet. Brit. J. Nutrition, 13: 178. 1959.

(83) ROJAS, J., SCHWEIGERT, B. S., AND RUPEL, I. W. The Utilization of Lactose by the Dairy Calf Fed Normal or Modified Milk Diets. J. Dairy Sci., 31: 81. 1948.

(84) ROY, J. H. B. The Nutrition of the Early Weaned Calf. A Review. Dairy Sci. Abstrs., 20: 1. 1958.

(85) ROY, J. H. B., PALMER, J., SHILLAM, K. W. G., INGRAM, P. L., AND WOOD, P. C. The Nutritive Value of Colostrum for the Calf. 10. The Relationship Between the Period of Time that a Calf House has been Occupied and the Incidence of Scouring and Mortality in Young Calves. Brit. J. Nutrition, 9: 11. 1955.

(86) RUPEL, I. W. Raising the Dairy Calf. Wisconsin Agr. Expt. Sta., Bull. 404. 1929.

(87) SAVAGE, E. S., AND McCAY, C. M. The Nutrition of Calves. A Review. J. Dairy Sci., 25: 595. 1942.

(88) SCHALK, A. F., AND AMADON, R. S. Physiology of the Ruminant Stomach. Bovine. North Dakota Agr. Expt. Sta., Bull. 216. 1928.

(89) SCHMIDT, J., AND KLIESCH, J. Further Calf-Raising Trials. Forsch Dienst, 15: 83. 1943. (Dairy Sci. Abstrs., 6: 20. 1944-45.)

(90) SEEKLES, L., AND WEGELIN, E. Value of Whey with a Diminished Salt and Lactose Content as a Source of Protein in the Feeding of Animals. IX. Congr. Internaz. Ind. Agrar., Rome, 14. 1952. (Nutrition Abstr. & Revs., 23: 198. 1953.)

(91) SELLERS, K. C., AND EDEN, E. The Effect of White Scour on the Absorption of Vitamin A by Calves. J. Comp. Path., 59: 205. 1949.

(92) SHAW, R. H., WOODWARD, T. E., AND NORTON, R. P. Digestion of Starch by the Young Calf. J. Agr. Research, 12: 575. 1918.

(93) SHEEHY, E. J. Derangement of the Digestive Process in the Milk Fed Calf Due to Abnormal Curd Formation in the Fourth Stomach. Roy. Dublin Soc. Sci. Proc., 21: 73. 1934.

(94) SHOPTAW, L. Soybean Flour as a Substitute for Cow's Milk in Feeding Dairy Calves. J. Dairy Sci., 19: 95. 1936.

(95) SHOPTAW, L. ESPE, D. L., AND CANNON, C. Y. Gastric Digestion of Soybean Flour. J. Dairy Sci., 20: 117. 1937.

(96) SOLLMANN, T. A Manual of Pharmacology and its Applications to Therapeutics and Toxicology. 7th ed. W. B. Sanders Co., Philadelphia. London. 1948.

(97) SPIELMAN, A. A., LOOSLI, J. K., NORTON, C. L., AND TURK, K. L. Carotene Utilization in the Newborn Calf. J. Dairy Sci., 29: 381. 1946.

(98) STATLAND, H. Fluid and Electrolytes in Practice. 2nd ed. J. B. Lippincott Company, Philadelphia. Montreal. 1957.

(99) STEIN, J. F., KNODT, C. B., AND ROSS. E. B. Use of Special Processed Soybean Flour and Whey Solubles in Milk Replacement Formulas for Dairy Calves. J. Dairy Sci., 37: 373. 1954.

(100) UDALL, D. H. The Practice of Veterinary Medicine. 6th ed. Ithaca, New York. 1954.

(101) VELU, J. G., GARDNER, K. E., AND KENDALL, K. A. Utilization of Various Sugars by the Young Dairy Calf. (Abs.) J. Dairy Sci., 42: 920. 1959.

(102) WALLACE, H. D., LOOSLI, J. K., AND TURK, K. L. Substitutes for Fluid Milk in Feeding Dairy Calves. J. Dairy Sci., 34: 256. 1951.

(103) WILLIAMS, J. B., AND JENSEN, C. Hydrated Lime In Milk Replacements. North Dakota Agr. Expt. Sta., Bi-Mo. Bull., 5: 167. 1955.

(104) WILLIAMS, J. B., AND KNODT, C. B. A P F Supplements in Milk Replacements for Dairy Calves. J. Animal Sci., 10: 144. 1951.

(105) WING, J. M., JACOBSON, N. L., AND ALLEN, R. S. The Effect of Various Restricted Diets on the Growth and on Certain Blood Components of Young Dairy Calves. J. Dairy Sci., 38: 1006. 1955.

(106) WINSLOW, K. Veterinary Materia and Therapeutics. 7th ed. Wm. R. Jenkins Co., New York City. 1916.

(107) WISE, G. H. Dried Whey in the Ration of Unthrifty Dairy Calves. Rep. S. C. Agric. Expt. Sta., 84. 1940-41. (Dairy Sci. Abstrs., 5: 29. 1943.)

(108) WISE, G. H., AND ANDERSON, G. W. Factors Affecting the Passage of Liquids into the Rumen of the Dairy Calf. I. Method of Administering Liquids: Drinking from Open Pail Versus Sucking through a Rubber Nipple. J. Dairy Sci., 22: 697. 1939.

(109) WISE, G. H., ANDERSON, G. W., AND MILLER, P. G. Factors Affecting the Passage of Liquids into the Rumen of the Dairy Calf. II. Elevation of the Head as Milk is Consumed. (Abs.). J. Dairy Sci., 25: A115. 1942.

(110) WISE, A. C., JOHNSON, B. C., MITCHELL, H. H., AND NEVENS, W. B. Synthetic Rations for the Dairy Calf. J. Dairy Sci., 30: 87. 1947.

(111) YOUNG, F. B. Response of Dairy Calves to Whole Milk Replacements Containing Dried Whey Product, Dried Skimmilk and Fat. (Abs.). J. Dairy Sci., 36: 600. 1953.

APPENDIX

TABLE VIII

COMPOSITION OF ANTIBIOTIC AND TRACE MINERAL SUPPLEMENT[a]

Ingredient	Quantity mg.
$FeSO_4$ (anhydrous)	945.0
$CuSO_4$ (anhydrous)	178.0
$MnSO_4 \cdot H_2O$	683.0
Bactracin	210.0
Penicillin	84.0

[a]2.1 g. added to each 85 lb. of milk.

TABLE IX

COMPOSITION OF ANTIBIOTIC AND VITAMIN SUPPLEMENT[a]

Ingredient	Quantity	Remarks[b]
Vitamin A	5000 I U	0.50 g. Quadrex
Vitamin D	625 I U	containing A and D
Thiamine	20.0 mg.	
Riboflavin	20.0 mg.	
Pyridoxine	10.0 mg.	
Ca Pantothenate	10.0 mg.	40.0 mg.
Niacin	20.0 mg.	
Inositol	100.0 mg.	
Biotin	0.2 mg.	
p-Aminobenzoic acid	12.0 mg.	
Alpha-D-tocopherol	20.0 mg.	454 mg.
Folic acid	1.0 mg.	
Menadione	1.0 mg.	
Vitamin B_{12}	0.01 mg.	10 mg.
Chlortetracycline	60.0 mg.	5.54 g. Aurofac D

[a] Each calf received 6.3 g. of the supplement along with the milk at the morning feeding each day.

[b] Indicates the amounts of material added for those ingredients previously premixed in a carrier.

TABLE X

AVERAGE DAILY FECAL INDICES FOR CALVES FED EXPERIMENTAL DIETS FOR 14 DAYS

Days on Experiment	Treatment group[a]				All groups[b]
	1	2	3	4	
1	1.50	1.00	2.00	2.75	1.81
2	1.50	4.75	15.75	4.25	6.56
3	4.75	4.75	16.25	17.75	10.88
4	2.75	5.25	8.25	16.25	8.13
5	4.75	10.00	2.75	20.50	9.50
6	15.75	11.25	2.50	47.25	19.19
7	15.25	8.25	7.00	32.50	15.75
8	4.00	3.50	14.25	18.25	10.00
9	18.25	3.50	7.75	15.00	11.13
10	6.75	10.75	10.50	11.75	9.94
11	10.25	4.00	13.50	5.50	8.31
12	20.75	3.00	10.00	12.25	11.50
13	16.25	1.50	16.00	10.75	11.13
14	10.50	2.50	5.50	11.75	7.56
	9.50	5.29	9.43	16.18	10.10

[a] Group 1: Skimmilk; Group 2: Skimmilk and Fat; Group 3: Skimmilk and Minerals; Group 4: Skimmilk, Fat and Minerals

[b] Average of 16 calves

TABLE XI

AVERAGE DAILY FECAL INDICES FOR CALVES
FED EXPERIMENTAL DIETS FOR 21 DAYS

Days on Experiment	Treatment group[a] 1	2	3	4	All groups[b]
1	5.25	1.50	2.00	1.00	2.44
2	7.50	1.50	4.75	1.25	3.75
3	4.75	4.75	13.00	6.50	7.25
4	6.50	3.75	13.25	7.50	7.75
5	4.75	11.75	18.25	10.50	11.31
6	2.25	9.75	25.00	29.00	16.50
7	2.00	13.50	31.50	42.50	22.38
8	8.00	10.25	26.00	35.25	19.88
9	10.50	10.25	27.25	37.00	21.25
10	12.75	5.25	33.00	25.75	19.19
11	14.50	9.50	28.50	22.50	18.75
12	8.00	20.25	18.00	14.25	15.13
13	16.50	23.50	16.75	23.75	20.13
14	16.50	9.00	17.50	11.00	13.50
15	9.25	6.50	15.25	7.75	9.69
16	8.50	4.25	14.50	2.25	7.38
17	10.50	6.00	9.50	1.75	6.94
18	12.50	2.75	12.00	2.75	7.50
19	14.75	7.50	12.00	3.50	9.44
20	12.00	4.50	6.75	5.25	7.13
21	3.50	6.00	7.50	3.75	5.19
	9.08	8.19	16.77	14.04	12.02

[a] Group 1: Skimmilk; Group 2: Skimmilk and Fat; Group 3: Skimmilk and Minerals; Group 4: Skimmilk, Fat and Minerals

[b] Average for 16 calves

TABLE XII

INITIAL AND FINAL BODY WEIGHTS AND HEMATOCRIT VALUES OF CALVES RECEIVING EXPERIMENTAL DIETS FOR 14 DAYS.

Group[a]	Calf No.	Body Weight Initial	Body Weight Final	Hematocrit Values, Day of Experiment 1	5	10	13
		(lb.)	(lb.)	(%)	(%)	(%)	(%)
1	2	84	81	32.0	----	43.5	----
	10	85	79	41.0	43.0	43.5	47.5
	13	85	84	29.4	29.5	27.5	29.0
	18	84	85	20.0	22.0	42.0	24.4
2	1	100	100	43.0	40.0	43.0	----
	6	84	88	33.0	33.5	33.7	34.0
	11	89	90	36.0	37.1	38.9	36.0
	12	82	93	29.0	33.8	34.0	32.0
3	4	93	95	----	28.5	26.5	27.8
	9	99	95	38.0	37.0	41.0	36.6
	14	90	88	40.5	----	45.0	44.0
	17	84	82	32.8	32.0	34.0	34.0
4	3	92	97	34.0	----	37.0	39.0
	8	98	103	40.0	40.0	41.0	42.0
	15	99	89	34.1	35.0	37.2	36.5
	42	77	77	30.0	27.5	30.0	29.0

[a] Group 1: Skim; Group 2: Skim and Fat; Group 3: Skim and Minerals; Group 4: Skim, Fat and Minerals

TABLE XIII

INITIAL AND FINAL BODY WEIGHTS AND HEMATOCRIT VALUES OF CALVES RECEIVING EXPERIMENTAL DIETS FOR 21 DAYS.

Group[a]	Calf No.	Body Weight Initial	Body Weight Final	Hematocrit Values, Day of Experiment 1	5	9	13	17	21
		-----(lb.)-----		----------------(%)----------------					
1	21	98	100	38.0	----	36.0	----	----	----
	25	89	89	36.0	36.0	----	34.5	34.5	34.5
	27	91	83	----	34.4	35.0	33.0	34.0	37.0
	30	80	78	40.0	41.3	40.0	40.0	42.0	40.0
2	26	92	93	32.0	36.0	38.0	38.0	38.0	38.0
	22	86	89	21.0	----	29.5	----	29.5	32.0
	33	67	69	29.5	31.0	33.0	32.0	31.0	33.5
	37	97	94	32.5	34.0	41.3	40.0	36.0	40.0
3	29	109	102	38.0	40.2	41.0	41.0	39.0	43.5
	28	100	100	44.0	43.0	45.0	46.0	45.0	49.0
	35	87	73	28.0	----	34.3	37.0	34.0	35.0
	36	88	84	41.5	41.0	40.5	40.0	39.0	41.0
4	20	97	99	44.0	44.9	46.5	48.0	49.0	49.0
	24	97	103	38.5	38.5	----	40.0	40.0	38.5
	38	94	102	41.0	41.0	41.0	44.0	36.1	41.0
	39	88	91	38.9	39.7	40.0	40.4	40.2	42.5

[a] Group 1: Skim; Group 2: Skim and Fat; Group 3: Skim and Minerals; Group 4: Skim, Fat and Minerals

TABLE XIV

pH OF THE DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.

				Small Intestine		Large Intestine	
Group[a]	Calf No.	Rumen	Abomasum	Seg.I	Seg.II	Seg.I	Seg.II
1	2	6.5	4.7	5.8	6.9	5.9	5.7
	10	6.7	4.4	6.5	6.7	5.8	5.3
	13	5.5	3.1	5.8	6.8	5.8	6.7
	18	6.1	2.7	4.8	7.0	4.9	6.2
	Av.	6.2	3.7	6.0	6.9	5.6	6.0
2	1	6.4	4.9	5.9	6.4	5.9	5.6
	6	6.8	2.5	6.6	6.8	5.3	7.2
	11	6.3	2.5	6.2	6.9	5.2	6.9
	12	6.1	2.8	6.1	6.7	5.4	6.8
	Av.	6.4	3.2	6.2	6.7	5.5	6.6
3	4	6.7	4.4	6.0	7.0	5.7	6.6
	9	6.6	5.4	6.9	6.4	5.1	6.1
	14	6.2	3.6	6.1	7.0	5.6	6.4
	17	6.3	4.1	6.0	6.9	5.5	6.2
	Av.	6.5	4.4	6.3	6.8	5.5	6.3
4	3	5.6	3.0	6.1	6.8	5.8	6.7
	8	6.2	4.0	6.4	5.8	6.0	6.5
	15	6.2	3.7	5.8	6.6	5.2	6.4
	42	5.9	3.4	6.2	7.2	5.4	5.9
	Av.	6.0	3.5	6.1	6.6	5.6	6.4

[a] Group 1: Skim — Group 2: Skim and Fat — Group 3: Skim and Minerals — Group 4: Skim, Fat and Minerals

TABLE XV

TOTAL WEIGHT OF DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.[a]

Group[b]	Calf No.	Rumen g.	Abomasum g.	Small Intestine Seg.I g.	Small Intestine Seg.II g.	Large Intestine Seg.I g.	Large Intestine Seg.II g.
1	2	124.4	348.2	81.0	204.7	150.6	342.8
	10	215.3	98.4	112.8	253.7	171.6	200.5
	13	816.9	505.7	285.9	449.0	189.3	76.4
	18	409.0	235.8	235.6	335.0	280.9	183.2
	Av.	391.4	297.0	178.8	310.6	198.1	200.7
2	1	639.4	434.1	424.8	538.7	291.7	171.5
	6	488.0	480.8	320.4	349.2	87.0	47.6
	11	544.9	217.7	439.1	148.8	19.5	70.7
	12	376.1	271.4	211.1	259.7	137.6	49.6
	Av.	512.1	351.0	348.8	324.1	134.0	84.9
3	4	436.9	303.8	142.0	304.0	185.5	239.5
	9	491.4	381.9	353.3	227.3	582.4	293.5
	14	482.6	321.1	148.0	197.5	207.9	257.5
	17	557.3	348.3	147.1	215.9	175.9	51.9
	Av.	492.1	338.8	197.6	236.2	287.9	210.6
4	3	549.5	225.8	354.7	197.0	168.6	193.2
	8	510.7	261.0	304.9	245.3	284.9	99.5
	15	595.4	459.0	323.4	367.8	247.4	148.8
	42	414.0	150.8	248.6	171.3	438.7	234.3
	Av.	517.4	274.1	307.9	245.3	284.9	169.0

[a] Wet basis

[b] Group 1: Skim; Group 2: Skim and Fat; Group 3: Skim and Minerals; Group 4: Skim, Fat and Minerals

TABLE XVI

DRY MATTER IN THE DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.

Group[a]	Calf No.	Rumen %	Abomasum %	Small Intestine Seg.I %	Small Intestine Seg.II %	Large Intestine Seg.I %	Large Intestine Seg.II %
1	2	1.63	14.31	15.11	5.43	5.28	4.06
	10	1.15	21.64	9.50	7.76	8.05	11.88
	13	2.99	13.20	7.61	3.55	4.77	10.75
	18	1.32	12.57	6.93	6.51	6.67	13.17
	Av.	1.77	15.32	9.79	5.81	6.19	9.97
2	1	3.13	20.29	7.63	5.72	4.40	5.92
	6	1.63	8.90	9.29	9.83	8.86	12.29
	11	1.59	3.23	9.33	11.21	14.37	25.82
	12	1.36	11.83	12.53	7.51	6.45	18.06
	Av.	1.93	11.06	9.70	8.57	8.52	15.52
3	4	1.62	13.17	10.73	5.70	4.67	8.99
	9	1.23	21.36	3.77	4.85	4.33	7.51
	14	1.47	14.01	10.55	7.29	5.90	15.16
	17	1.63	15.05	10.15	8.35	6.06	11.99
	Av.	1.49	15.90	8.80	6.55	5.24	10.91
4	3	2.03	7.63	8.57	7.69	5.62	11.73
	8	2.05	9.26	11.04	7.67	7.67	11.41
	15	1.43	5.43	12.15	9.35	8.02	18.00
	42	1.67	3.80	6.95	5.36	7.61	14.82
	Av.	1.80	6.53	9.68	7.52	7.23	13.99

[a] Group 1: Skim
Group 2: Skim and Fat
Group 3: Skim and Minerals
Group 4: Skim, Fat and Minerals

TABLE XVII

PROTEIN IN THE DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.[a]

Group[b]	Calf No.	Rumen %	Abomasum %	Small Intestine Seg.I %	Small Intestine Seg.II %	Large Intestine Seg.I %	Large Intestine Seg.II %
1	2	39.88	64.22	65.32	65.56	68.94	57.14
	10	44.34	70.74	58.00	44.84	29.68	52.35
	13	36.45	32.72	41.65	32.67	46.75	59.91
	18	39.39	65.15	58.15	43.93	50.82	70.23
	Av.	40.01	58.21	55.78	46.75	49.05	59.91
2	1	23.32	52.69	48.62	48.25	32.27	39.87
	6	44.79	32.13	51.99	38.45	42.44	43.21
	11	50.66	20.15	10.71	9.72	8.82	8.04
	12	46.32	27.81	36.39	42.48	36.59	43.31
	Av.	41.27	33.20	36.84	34.98	30.03	33.61
3	4	35.19	65.00	65.80	49.65	35.55	36.37
	9	33.35	57.91	44.03	50.72	41.80	52.53
	14	43.80	60.17	61.04	51.58	38.64	33.25
	17	43.55	47.74	63.45	48.74	41.74	56.79
	Av.	38.95	57.71	58.58	50.17	39.43	44.74
4	3	35.96	35.53	51.81	49.67	38.26	38.45
	8	39.32	35.21	44.20	61.67	42.89	51.53
	15	37.06	31.12	45.10	42.35	31.55	37.17
	42	42.51	33.68	58.99	51.49	40.60	45.95
	Av.	38.71	33.88	50.02	51.30	38.33	43.28

[a] All values expressed on a moisture-free basis.

[b] Group 1: Skim; Group 2: Skim and Fat; Group 3: Skim and Minerals; Group 4: Skim, Fat and Minerals

TABLE XVIII

FAT IN THE DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.[a]

Group[b]	Calf No.	Rumen %	Abomasum %	Small Intestine Seg. I %	Small Intestine Seg. II %	Large Intestine Seg. I %	Large Intestine Seg. II %
1	2	26.38	3.42	6.02	0.92	2.46	6.40
	10	4.35	.32	3.16	0.00	0.00	2.20
	13	21.74	33.71	18.00	2.53	11.32	6.05
	18	0.00	0.00	4.76	0.00	0.00	2.12
	Av.	13.12	1.24	4.64	1.15	3.45	3.57
2	1	0.00	14.98	14.29	7.87	6.59	11.32
	6	11.00	31.80	16.90	7.02	9.14	8.05
	11	0.00	26.01	15.54	7.67	8.49	5.42
	12	8.09	59.65	15.56	12.92	2.01	----
	Av.	6.36	33.11	15.57	8.87	6.56	6.20[c]
3	4	0.00	0.00	7.36	4.39	7.92	4.56
	9	0.00	0.19	0.79	1.86	0.00	1.46
	14	0.00	0.14	6.92	0.00	0.85	3.63
	17	3.05	0.47	4.24	0.96	1.49	1.92
	Av.	0.76	0.20	4.70	1.80	2.57	2.89
4	3	17.24	31.19	16.69	19.12	11.57	9.46
	8	3.41	32.29	4.44	8.73	4.56	4.03
	15	0.00	25.97	24.28	6.84	9.10	4.00
	42	0.00	13.95	7.91	2.43	19.32	14.24
	Av.	5.12	25.85	13.15	9.28	11.14	7.93

[a] All values expressed on a moisture-free basis.

[b] Group 1: Skim — Group 3: Skim and Minerals
Group 2: Skim and Fat — Group 4: Skim, Fat and Minerals

[c] Average of 3 calves only.

TABLE XIX

N-FREE EXTRACT IN THE DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.[a]

				Small Intestine		Large Intestine	
Group[b]	Calf No.	Rumen %	Abomasum %	Seg.I %	Seg.II %	Seg.I %	Seg.II %
1	2	00.00	24.72	22.47	15.94	11.91	16.55
	10	00.00	21.03	27.91	42.99	59.77	29.34
	13	13.90	29.48	29.72	45.11	22.98	21.33
	18	2.40	27.07	24.68	41.79	35.43	12.72
	Av.	4.07	25.57	26.20	36.45	32.40	19.87
2	1	56.24	25.72	24.92	28.90	44.13	35.28
	6	00.00	30.16	22.80	40.42	37.45	34.15
	11	9.09	15.45	22.41	40.24	27.02	28.21
	12	00.00	8.25	40.10	30.10	47.73	----
	Av.	16.33	19.90	27.56	34.96	39.08	32.55
3	4	5.41	21.61	16.83	20.95	15.61	16.18
	9	1.20	21.33	26.23	25.97	27.37	15.74
	14	5.10	10.07	21.34	27.13	26.04	21.63
	17	0.00	24.04	17.53	30.83	34.66	15.28
	Av.	29.28	19.26	48.25	26.22	25.92	17.20
4	3	8.73	21.24	20.25	15.05	19.96	22.30
	8	9.58	20.51	29.54	17.23	23.88	20.29
	15	9.35	25.60	20.61	28.08	27.67	25.84
	42	16.40	37.60	22.87	21.92	12.07	18.42
	Av.	11.02	26.24	23.32	20.57	20.90	21.71

[a] All values expressed on a moisture-free basis.

[b] Group 1: Skim; Group 2: Skim and Fat; Group 3: Skim and Minerals; Group 4: Skim, Fat and Minerals

TABLE XX

ASH IN THE DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.[a]

Group[b]	Calf No.	Rumen %	Abomasum %	Small Intestine Seg.I %	Small Intestine Seg.II %	Large Intestine Seg.I %	Large Intestine Seg.II %
1	2	52.17	7.64	6.19	17.58	16.67	19.91
	10	53.21	7.91	10.93	12.07	10.55	16.11
	13	27.91	4.09	10.63	19.69	18.95	12.71
	18	58.21	7.68	12.41	14.28	13.75	14.93
	Av.	47.88	6.83	10.04	15.91	14.89	15.92
2	1	20.44	6.61	12.17	14.98	17.01	13.53
	6	45.46	5.91	8.31	14.11	10.97	14.59
	11	50.66	20.15	10.71	9.72	8.82	8.04
	12	56.26	4.29	7.95	13.50	13.57	16.31
	Av.	43.21	9.24	9.79	13.08	12.59	13.09
3	4	59.40	13.39	10.01	25.01	40.92	42.89
	9	65.45	20.57	28.95	21.45	30.83	30.47
	14	51.10	15.61	10.70	21.29	34.47	41.49
	17	54.85	17.65	14.78	19.37	22.11	26.01
	Av.	59.50	16.81	16.11	21.78	32.08	35.22
4	3	38.07	12.05	11.25	16.16	30.21	29.79
	8	47.69	11.99	21.82	12.37	28.67	24.15
	15	53.59	17.31	10.01	22.73	31.68	32.99
	42	41.09	14.77	10.23	24.66	28.01	21.39
	Av.	45.11	14.03	13.35	19.98	29.64	27.08

[a] All values expressed on a moisture-free basis.

[b] Group 1: Skim — Group 3: Skim and Minerals
Group 2: Skim and Fat — Group 4: Skim, Fat and Minerals

TABLE XXI

TOTAL AMOUNT OF DIFFERENT CONSTITUENTS IN DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.

Group[a]	Rumen g.	Abomasum g.	Small Intestine Seg.I g.	Small Intestine Seg.II g.	Large Intestine Seg.I g.	Large Intestine Seg.II g.
			(Total Contents)[b]			
1	391.4	297.0	178.8	310.6	198.1	200.7
2	512.1	351.0	348.8	324.1	134.0	84.9
3	492.1	338.8	197.6	236.2	287.9	210.6
4	517.4	260.9	307.9	245.3	284.9	169.0
			(Dry Matter)			
1	8.6	41.9	17.9	17.1	17.4	17.5
2	10.4	42.5	32.3	25.3	8.1	10.8
3	7.3	54.8	14.8	15.2	14.2	22.2
4	9.3	17.3	30.2	19.4	21.4	21.0
			(Protein)[c]			
1	3.2	22.1	9.3	7.7	8.2	7.0
2	3.7	17.6	11.3	9.5	2.7	3.0
3	0.4	31.3	8.7	7.6	5.7	9.0
4	3.6	5.9	14.6	9.6	8.2	9.0
			(Fat)[c]			
1	1.5	6.1	1.9	0.1	0.8	0.6
2	0.3	11.9	5.0	2.1	0.5	0.9[d]
3	0.3	0.1	0.7	0.3	0.2	0.7
4	0.6	5.0	4.4	1.8	2.6	0.9

[a] Group 1: Skim; Group 2: Skim and Fat; Group 3: Skim and Minerals; Group 4: Skim, Fat and Minerals

[b] Wet basis

[c] All values expressed on a moisture-free basis.

[d] Average of three calves only.

Table XXI (continued)

Group[a]	Rumen g.	Abomasum g.	Small Intestine Seg.I g.	Small Intestine Seg.II g.	Large Intestine Seg.I g.	Large Intestine Seg.II g.
			(N F E)[c]			
1	0.1	3.8	2.5	2.1	2.2	2.0
2	0.5	3.5	1.8	3.1	3.1	3.4
3	0.1	3.1	1.7	1.8	1.4	1.9
4	0.2	1.6	2.3	1.6	1.5	3.1
			(Ash)[c]			
1	3.1	2.6	1.9	2.6	2.7	2.8
2	3.7	2.8	3.2	3.4	1.2	1.3
3	4.2	7.1	2.3	3.3	5.9	5.9
4	4.1	2.4	4.1	3.7	6.2	5.6

TABLE XXII

ANALYSIS OF VARIANCE ON pH OF DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.

Source of Variation[a]	Degrees of Freedom	Mean Square	F
Segment (S)	5	19.1000	75.64[b]
Diets (D)	3	0.3133	1.24
S x D	15	0.2627	1.04
Error	72	0.2525	

[a] Interactions not approaching statistical significance omitted from table.
[b] $P < 0.005$

TABLE XXIII

ANALYSIS OF VARIANCE ON TOTAL WEIGHT OF DIGESTIVE TRACT CONTENTS OF CALVES SACRIFICED AT 17 DAYS OF AGE.

Source of Variation[a]	Degrees of Freedom	Mean Square	F
Segment (S)	5	180,867.4	12.06[b]
Diets (D)	3	6,614.3	0.44
S x D	15	16,617.7	1.11
Error	72	14,998.5	

[a] Interactions not approaching statistical significance omitted from table.
[b] $P < 0.005$

VITA

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Doctor of Philosophy

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