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Observations of jersey and holstein calves with special attention to rumination and rumen development

James David Harris

To the Graduate Council:

I am submitting herewith a thesis written by James David Harris entitled "Observations of jersey and holstein calves with special attention to rumination and rumen development." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.

Eric W. Swanson, Major Professor

We have read this thesis and recommend its acceptance:

Henry A. Fribourg, C.E. Wylie, Louis J. Boyd

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(Original signatures are on file with official student records.)

July 12, 1957

To the Graduate Council:

I am submitting herewith a thesis written by James David Harris, Jr. entitled "Observations of Jersey and Holstein Calves With Special Attention to Rumination and Rumen Development." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Dairying.

Eric W. Swanson
Major Professor

We have read this thesis
and recommend its acceptance:

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Accepted for the Council:

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OBSERVATIONS OF JERSEY AND HOLSTEIN CALVES WITH SPECIAL ATTENTION TO RUMINATION AND RUMEN DEVELOPMENT

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

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by

James David Harris, Jr.

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INTRODUCTION

The rumen plays an important part in the digestive process of the bovine species. Here the feed after being swallowed is stored, mixed, and softened with water and saliva, as well as subjected to bacterial action which aids in digestion. Because of the very important role of the rumen in bovine nutrition, it becomes increasingly important to study the development of this organ in the young animal.

A study of the young bovine stomach is of interest as it may relate to early feeding possibilities and to potential development and function. The earlier calves can be induced to efficiently utilize roughage the more economical a calf feeding program will be. Economy and efficiency in feeding the ruminant are based fundamentally on taking full advantage of rumen function with particular emphasis on the development which results in better digestion of roughages and the synthesis of high quality proteins and vitamins.

Although there has been extensive research on ruminants of various ages there is only a limited amount of critical knowledge of the factors affecting the development of the fore-stomach of calves and the importance that should be attached to this development. No reports based

upon direct observations have been found which specifically outline the development of rumination.

In the investigation reported here young Jersey and Holstein calves were observed at intervals during early growth to note the various activities with special emphasis upon rumination. From these observations it was possible to get a picture of the progression of rumination as the calf matured. Several young ruminating and nonruminating calves were slaughtered for observations of the development of the digestive organs. The amount of glucose in the blood of a group of calves was determined and these data also were used as an indication of rumen development.

REVIEW OF LITERATURE

Early work. The major investigations of calf nutrition up to 1940 have been reviewed by Savage (50). In this review it was stated that Spallanzani made some studies concerning chewed and non-chewed food in oxen as early as 1800. He found that chewed foods were easily digested in the rumen; whereas, unchewed foods were slowly digested. It was also stated that Tiedmann and associates in 1826 found that milk fed to calves passed directly into the fourth stomach. These investigators also found that certain gases and acids were produced in the rumen after the feeding of hay. Early work in England concerned with ruminant digestion was the feeding of perforated silver spheres containing food material and comparing the rate at which the contents were dissipated.

Some of the first work in the twentieth century was devoted to the study of vitamin B, commonly referred to as a growth promoting vitamin. Workers as early as 1922 concluded that the absence of this factor from the diets of animals led to impaired growth and undermining of health and vigor. This also had an effect on the ability of a mother to raise young (3).

Fetal development of the ruminant stomach. Thirty-four pregnant Jersey cows were slaughtered by Becker,

DixArnold, and Marshall (4) for observations of the fetuses with emphasis on size and weight of the stomach. They found that up to 59 days after conception, the reticulum was not sufficiently differentiated for a satisfactory gross separation from the rumen. In 4-month-old fetuses the rumen dominated in weight and was 2 to 3 times the weight of the abomasum. After this point the abomasum began to increase in weight more rapidly than did the other compartments of the stomach. At full term, the abomasum was found to weigh nearly as much as the other compartments combined.

During early fetal life the omasum ranked second to the rumen in weight, but generally was heavier than the abomasum up to 5.5 months. At 7.5 months the omasum was a less prominent part of the total stomach. The rumen had attained double the weight of the omasum at the time of birth. Table I gives a comparison of weights of the stomach compartments at different fetal ages (4).

Postnatal development of the ruminant stomach. The fact that the abomasum in the newborn calf is considerably larger in weight and capacity than the rumen has been reported by several workers (17, 31, 35, 51, 52).

Sisson and Grossman (52) reported that the reticulorumen constitutes about one third of the total stomach capacity at birth and that it increases to about 85% at

TABLE I

EMPTY WEIGHTS OF FETAL STOMACH COMPARTMENTS AT DIFFERENT AGES [a]

Days after conception	Rumen	Reticulum	Omasum	Abomasum	Total
	(g.)	(g.)	(g.)	(g.)	(g.)
72	0.19	0.09	0.16	0.09	0.53
81	0.67	0.15	0.44	0.39	1.56
93	1.69	0.40	0.99	0.72	3.80
100	2.73	0.62	1.95	0.83	6.13
109	4.28	0.65	2.78	1.45	9.16
118	4.16	0.64	2.82	1.38	9.00
127	4.12	1.64	4.12	3.47	16.35
138	11.51	2.37	8.07	6.40	28.35
148	12.62	3.86	8.80	8.34	33.62
151	13.52	2.93	12.07	7.85	36.37
177	27.46	5.32	16.09	25.67	74.54
186	31.88	8.38	26.82	37.03	104.00
204	43.13	12.03	33.70	46.77	135.63
228	73.56	16.69	34.10	87.33	211.68
236	70.75	20.19	40.20	85.23	216.37
250	68.00	14.50	19.00	66.00	167.50

[a] From Becker, R. B., et al. J. Dairy Sci., 34: 329. 1951.

maturity. According to Grossman (17) the first three stomach compartments have about half the capacity of the abomasum at birth.

McNeill and associates (40) have observed that rumen fluid of the newborn calf is a mixture of bacteria, protozoa, plant fragments, soil, and many chemical compounds, both substrates and end products in aqueous solution and suspensions. At the time of birth of the calf, all sections of the alimentary tract contain a mixture of fluids and various solids including hair.

The following criteria indicative of rumen development have been suggested by Lengeman and Allen (34):

1. Some measure of the ability to digest cellulose
2. A description of the more characteristic types of bacteria
3. A measure of some of the rumen acids
4. An estimate of the total bacterial population
5. Numbers of protozoa

These workers collected rumen samples from at least five animals from each of the following age groups: 0 to 1 month, 1 to 2 months, 2 to 3 months, 5 to 6 months, 10 to 12 months, and lactating cows over 2 years old. A stomach tube was used in obtaining samples 6 hours after feeding. The samples were squeezed to about 24% dry matter. The liquid portion was used for protozoa counts, cellulose

digestion, and rumen acid determinations. The dry portion was used for identification and determination of total numbers of different types of bacteria. No great differences were found among animals over 6 months old according to these criteria.

The method of feeding liquids to calves appears to be important as related to postnatal development of the rumen. It has been shown that liquids go to the rumen in abnormal amounts when the calf is fed from open pails. The esophageal groove is known to control to a certain extent the course of liquids. In describing the esophageal groove Duke (12) stated,

> The esophageal groove (reticular) functions as a conduit closure for milk or water on the way to the reticulo-omasal orifice. The reflex by which the groove is closed has been thought to diminish in sharpness as the animal matures.... The shift from the sucking desire to the thirst desire is significant in the mechanics of the esophageal groove.

The cause of the unthrifty appearance commonly observed in young dairy calves in modern dairy herds has been partially attributed to deviation from "nature's way" of feeding by Wise and Anderson (59). These workers used seven calves in each of two groups to study the effect of different milk feeding methods on the course of liquids to and through the stomach. One group was fed from an open pail and the other through a nipple bucket with a valve. In only 2.2% of the cases did milk flow into the rumen

when taken from the nipple pails. Up to 50% of the milk consumed from an open pail escaped into the rumen. Similar results were obtained from the drinking of water.

Dietary factors affecting rumen development. The diet is an important factor causing structural changes in the ruminant fore-stomach after birth. Calves subsisting on liquid diets have been shown to have undeveloped rumens (6, 32, 56). Blaxter et al. (6) reported that calves given roughage in addition to milk, developed larger rumens than milk-fed calves growing at the same rate. He also stated that roughage-fed animals have no significant increase in rumen tissue weight over the milk-fed animals. The increase in size was attributed to the stretching of tissues by the bulk of hay. Warner (57) supported this with some experimental evidence. At 3 days of age, 24 calves were taken from their dams and allotted to Groups I, II, and III. Two calves from each group were slaughtered at 4, 7, 10, and 13 weeks of age for stomach observations.

The following rations were fed:

Group I - Mineralized milk

Group II - Milk and dry calf starter

Group III - Milk plus hay

Reticulo-rumen volumes (liters per 45.4 kg. of empty body weight) were determined at 4 and 13 weeks of age for the respective groups. They were: I - 3.7, 3.2;

II - 5.8, 12.5; III - 4.4, 31.4; respectively. These data suggest that hay stretches these organs. Papillary development in the rumen walls was advanced equally well in Groups II and III, but Group I had only rudimentary papillae. This indicates that if rough material is required for rumen development, dry calf starter probably contains an adequate amount.

McCandlish (37) compared a milk diet with other diets as they affected rumen development. Six calves were used. The study was started at birth of the calves and they were fed experimentally to an age of 120 days. Three feed lots were set up. The calves in Lot I remained on the cow a few days, after which milk was fed three times daily in as large amount as could be handled. Salt was fed free choice. In addition to the above, Lot II had a free choice grain mix which consisted of five parts cracked corn, two parts ground oats, two parts wheat bran, and two parts linseed oil meal by weight. Lot III had all of the above, plus free access to good quality alfalfa hay. There was a significant difference among the three lots in growth. It was concluded that milk alone was not suitable for growth, but milk and grain gave even poorer results. The lot receiving alfalfa hay in addition to milk and grain gave superior rates of growth. The additional nutrients supplied by alfalfa hay was not the main reason for the

good results. The advantage was attributed to bulk which encouraged rumen synthesis of vitamins and other nutrients from the ration. Pounden and Hibbs (45) agreed with this conclusion. They found that rumen bacteria are poorly established when a high proportion of grain to hay is fed.

In another study Hibbs et al. (22) raised a group of Holstein calves to 6 months of age on a high roughage system in which the ratio of hay to grain was 3:2. Growth, as indicated by weight and height at withers, was slightly less than the Ragsdale (Mo.) standards. No significant difference was noted in feed utilization between the breeds during the whole 6-month period.

At the age of 12 to 16 weeks molasses was added to the ration and at the age of 18 to 26 weeks penicillin was supplemented. No significant benefit was produced by either of these in a 3:2 hay to grain mixture as measured by growth, feed consumption, or efficiency of feed utilization.

Eight female and four male grade calves were used in a study by Wise, Peterson, and Gullickson (60) aimed at exploring the effect of a whole milk diet. It was found that this caused anorexia, nervousness, and digestive disturbances. Blood was analyzed weekly for sugar, plasma fat, hemoglobin, and magnesium. A constantly high amount of blood sugar, extremes in fat of plasma, decrease in

hemoglobin, and a gradual downward trend of magnesium in plasma were found. These were all indicative of undeveloped rumens.

In a similar experiment Mead and Regan (41) fed six calves a normal grain ration which was void of any roughage. These calves were fed, in addition, the amount of alfalfa ash that would have been supplied in an alfalfa hay ration. Two other animals were used as controls. Among the many adverse effects were discharges from the nose and eyes. This was relieved by the administering of cod liver oil up to 19 months of age. There was also a marked calcium deficiency as weak bones persisted. These workers summarized by saying that calves could be raised to 19 months of age with normal growth on a no roughage ration provided they are supplemented with alfalfa ash and cod liver oil.

It has been demonstrated that vitamin B complex can be synthesized in the functional rumen of adult cattle (3, 9). Conrad (9) concluded as a result of sampling stomach materials from young calves by use of a stomach tube, that rumen synthesis occurred at a relatively high rate by the time the calves on a roughage feed system were eating 0.2 lb. of dry feed or by the time the calves were 3 weeks of age. Also it was concluded that the calves were synthesizing thiamine and riboflavin in adequate quantities by 7 weeks of age.

Twenty calves were fed normally on milk, grain, and hay by Kesler, Ronning, and Knodt (31) and slaughtered at intervals for rumen observations. There was a progressive increase in rumen contents and size from 1 to 4.5 weeks of age with no change in the abomasum. The pH was 5.5 to 5.6 for rumen contents and 3.4 to 4.0 for abomasal contents. Also in this study, 24 calves fed normal rations were slaughtered at 2, 4, 6, 8, 10, 12, 14, and 16 weeks for data on rumen contents, weights, and observations. All calves 6 weeks and older had normal adult-type rumen contents as shown by consistency, odor, and the small amount of free liquid present. Calves less than 6 weeks old had variable rumen contents. The greatest change in properties of the contents of the digestive tract occurred at 32 to 42 days of age. Fifteen calves that were fed only milk and milk replacement had liquid rumen contents with a foul odor, and a putrid odor in the lower intestines at 8 days of age.

After 4 days of age, calves born in the Ohio State University dairy herd were assigned by Hibbs and Pounden (24) to one of six feed groups as follows:

1. Alfalfa and cud inoculations
2. Alfalfa hay alone
3. Alfalfa, grain, and rumen inoculations
4. Alfalfa and grain

5. Alfalfa and calf starter

6. Whole milk only

Blood samples were taken weekly to 42 days of age and were analyzed for carotenoids and vitamin A. Rumen inoculations had no marked effect on blood carotenoid levels, but rations of alfalfa and whole milk resulted in higher levels after 14 days of age than were observed when grain was included in the ration. Neither inoculations nor the type of ration fed markedly influenced the plasma vitamin A levels. These results tend to indicate that palatable, high quality roughage stimulates the early development of rumen function in the young calf and appears to have a favorable physiological effect in meeting the vitamin needs of these animals.

In order to get more complete information about the practice of rumen inoculation, Conrad and associates (10) used balance trials in comparing the digestion of rumen inoculated and uninoculated calves. Ten male Jersey calves were divided into two groups. Group I was uninoculated and Group II was inoculated with small pieces of cud material from normal adult cattle. This material was placed in the mouth of the calves at 11, 16, and 21 days of age. Alfalfa hay was fed ad libitum to each group along with a normal grain ration. It was found that inoculation encouraged hay consumption at an earlier age than in

the uninoculated group. Group II digested a higher percentage of cellulose and other dry matter than did Group I, while there was no significant difference in protein digestion between Group I and II. The results of this study showed that rumen inoculations increased digestion of roughage at an early age.

Hibbs and associates (21) made studies of a low cost, high roughage system of raising calves based on early development of mature type rumen function. To one group of calves a 2:1 hay to grain ration was fed, and to a second group a 4:1 ratio was used. The hay was high quality grass-legume and the grain was a simple 14.5% protein mixture. To facilitate early rumination, rumen microorganisms were supplied through rumen inoculations. This was done by using fresh, warm cud material from healthy, mature cattle. In this system there was no advantage to feeding a complex calf starter ration, if a high quality and acceptable roughage was made available. Although significant, the difference between the weight gained by the 4:1 and 2:1 groups was small. The 2:1 hay to grain ratio showed more favorable gains.

The benefits of adding antibiotics to poultry and swine rations have been well established. Antibiotic feeding for ruminants is still of considerable interest to rumen nutritionists, physiologists, and bacteriologists (33).

In a recent study by Hibbs et al. (23), 24 Jersey calves (12 male and 12 female) were used to determine the effects of feeding aureomycin to calves raised on the high roughage system using three ratios of hay to grain. The ratios were 4:1, 3:2, and 2:3; each used in a separate group. There was also a control group. "Aurofac 2A" was fed at the rate of 15 mg. per day for the first 7 weeks and at 20 mg. per day per lb. of dry feed ingested for the remainder of the study.

Aureomycin increased growth and feed intake in all groups. However, the percentage of dry matter, cellulose, and protein digested was not influenced. Riboflavin content appeared higher in rumen juice and urine when aureomycin was fed, but the thiamine content was not affected. Aureomycin feeding practically eliminated the establishment of rumen bacteria in the 3:2 hay to grain group. These bacteria were well established in the control group. Increasing the amount of grain fed in relation to hay resulted in a progressive decrease in rumen bacteria in all hay to grain ratios, which is in agreement with other published results. This evidence suggests that the growth stimulation due to aureomycin feeding resulted from an alteration in energy metabolism, possibly involving the microflora and fauna of the rumen. Hogue et al. (26) are not in full agreement with the preceding study. They have

reported an increase in protein digestion and retention when aureomycin was fed. A difference in rations used in feeding the experimental animals could possibly cause this difference in results.

Raddison et al. (48) found in artificial rumen studies that rumen juice samples taken from aureomycin-fed calves had a lower digestion of filter paper cellulose with or without starch or grain, and/or when grass juice was added than did samples taken from calves not fed aureomycin. When alfalfa hay was substituted for filter paper, only a slight inhibition was noted.

Kesler and Knodt (30) added crystalline terramycin daily to the diet of six male Holstein calves at the rate of 20 mg. per 100 lb. of body weight. Three milk fed controls were also observed. The antibiotic was added to the milk ration up to 8 weeks of age. At this point the terramycin feeding was continued for three calves and stopped for the other three. The study lasted for 16 weeks. Terramycin gave a 22.7% increase in weight over the other milk replacement-fed calves, but gave no increase over the whole milk-fed group. The rumen samples were tested for cellulose digestion. The terramycin-fed calves had a lower digestion (24.2%) than did the control calves (67.4%).

Chemical changes due to rumen development. The development and functional changes that occur in the rumen

of the young dairy calf as it increases in age are not well understood. More work is needed concerning the metabolic utilization of the products resulting from microbial fermentation in the rumen.

Teeri, Keener, and Morrow (55) used Jersey, Guernsey and Holstein calves under 5 months of age in a study of the glucose and ascorbic acid of blood. The calves were fed a ration consisting of grain, hay ad libitum, and whole milk. Blood was collected for test from calves 4 weeks and younger, 5 to 8 weeks, 9 to 14 weeks, and 15 to 23 weeks of age. No significant difference was found between breeds at any age. The values found for glucose were 110 mg. per 100 ml. of blood for the 4-week-old group, 89.7 mg. per 100 ml. for the 5- to 8-week old group, 75.7 mg. per 100 ml. for the 9- to 14-week-old group, and 74.2 mg. per 100 ml. for the 15- to 23-week-old group. Ascorbic acid values were found to be 0.50 mg. per 100 ml. plasma for the 4-week-old group, 0.41 mg. per 100 ml. plasma for the 5- to 8-week-old group, 0.45 mg. per 100 ml. for the 9- to 14-week-old group, and 0.48 mg. per 100 ml. for the 15- to 23-week-old group.

This same general trend of blood glucose levels has been noted by other investigators (24, 32, 36, 49, 58). McCandless and Dye (36) studied glucose levels of several young domesticated and wild ruminants including sheep,

calves, goats, addax, antelope, aoudad, Asiatic deer, Dybowski's deer, eland, European red deer, Indian black buck, mouflon, and white tail deer. These animals were fed only their dam's milk the first week of the study with calf starter and hay free choice in the following weeks. Young ruminants were found to have high glucose levels in the "carnivore range" during the first few weeks of life. The averages were 97 mg. per 100 ml. blood for the first 10 days, 85 mg. per 100 ml. blood the second 10 days, 80 mg. per 100 ml. the third 10 days, 77 mg. per 100 ml. the fourth 10 days, and 61 mg. per 100 ml. the fifth 10 days.

The glycemic levels were inversely related to size and functional development of the rumen. The changes in blood glucose appeared as the young animals underwent a shift from milk to hay. These changes were believed to result from rumen bacterial changes and their incidental metabolism. Fasting ruminants were found to have a decrease in glycemic levels of the blood.

Dye (13) confirmed the above relationship and stated that during the first year of life, there exists an inverse relation between the glycemic level and functional development of the rumen in both domesticated and wild ruminants. Hyperglycemic curves following meals consisting of milk alone, were higher than when milk was supplemented with grain and hay.

Murley, Jacobson, and Allen (43) studied chemical changes of the blood using ten Holstein calves. They were fed 20% reconstituted skim milk, hay, and calf starter. Hay and concentrate were increased 2 lb. per week until a level of 1 lb. per feeding was reached. This ration was fed throughout the 12-week experimental period. Blood glucose decreased throughout the experiment. These authors have questioned the assumption that the glucose drop is associated with a dietary change because their calves were fed the same ration throughout the experimental period.

Twelve Jersey and nine Holstein calves were assigned by Hibbs et al. (24) to three groups varying only in ratios of hay to grain. The ration consisted of a normal calf starter and good alfalfa hay fed in 4:1, 2:3, and 3:2 hay to grain ratios. For comparison, four Jersey calves were fed exclusively on whole milk to 12 weeks of age. Fresh cud inoculations were given to all calves weekly for the first 6 weeks. Total fatty acids, pH of rumen contents, and blood glucose were used as an index for rumen development. Determinations were made at 4, 6, 9, and 12 weeks of age. Fatty acids were found to increase from 56 to 64 mg. per l. of rumen contents in the 4-week-old calves to a maximum of 84 to 99 mg. per l. at 9 weeks of age. It was noted that pH increased during this period at a higher rate and level for the higher hay to grain ratios, but the

difference between hay to grain groups was not significant. This suggests that the buffering capacity in the stomach increased as the hay intake increased. Blood glucose was found to range from 80 to 87 mg. % at 1 week of age and 52 to 58 mg. % at 8 weeks of age, after milk feeding was discontinued with no marked difference between hay to grain groups. A sharp decline in blood glucose came at 6 to 8 weeks of age, which was apparently associated with a reduction in milk feeding.

Six lambs of mixed breeds were used for blood analysis by Reid (49) in a rumen development study. Volatile fatty acids, blood glucose, and blood plasma glucose were determined weekly. Volatile fatty acids rose steadily with increasing age to 3 months of age, when the adult level was reached. The range was 4.0 to 14.0 mg. per 100 ml. blood. Blood glucose fell steadily as the calf aged until mature levels were reached. There was a 100% drop before the onset of rumination. Plasma glucose remained at a constant level for the first 3 weeks, then decreased. Corpuscle:plasma glucose ratios were 0.45:0.99 initially and declined to 0.03:0.39 and remained so until the eighth week.

Eight adult sheep were used to arrive at an adult corpuscle:plasma glucose level, which was 0:0.25. It was concluded that there is no close relationship between

glucose levels and rumen development. This conclusion is based on the following statements:

1. Glucose declines after the first week, but rumen development is negligible during the first 3 weeks. (The author did not mention the method used to determine the lack of rumen development.)
2. More than 50% of the glucose fall occurs before solid food is eaten. (The lambs were not deliberately fed any solid food although the author stated that they had free access to their dam's feed.)
3. A large proportion of the decline is due to the disappearance of glucose from the corpuscles, which starts at birth and is not associated with rumen development.

In a recent study by McCarthy and Kesler (38), glucose and volatile fatty acids in the blood of a group of calves were determined every 7 days. Glucose was found to be 113.4 mg. per 100 ml. of blood at 7 days of age, and steadily decreased to 43.9 mg. at 42 days of age. A range of 40 to 60 mg. was maintained throughout the remainder of the 16-week experiment. Total volatile fatty acids in the blood increased from 2.28 mg. per 100 ml. at 7 days of age to 6.24 mg. at 105 days of age.

This general trend has also been reported by other workers. Hodgson et al. (25) found no significant difference between breeds in levels of glucose in the blood of cows and found no effect of feeding time. Kennedy (29) in a more recent study, found blood glucose levels to rise sharply in calves directly after feeding. He concluded that there is little delay in lactose absorption in calves when milk is passed directly into the abomasum.

In a later study by McCarthy and Kesler (39), a report was made of the effect of diet on blood glucose and volatile fatty acids in Holstein calves. Three trials were set up with the only major difference being the ration supplied. The calves in trial 1 had 5 lb. of herd milk twice daily to 42 days of age and excellent quality alfalfa hay. Trial 2 was different from trial 1 in that a poorer quality mixed hay was supplied. Calves in trial 3 had 5 lb. of milk replacement twice daily with mixed hay. A steady decline in blood glucose was noted in the trial 1 calves. Those of trial 2 and 3 did not tend to decline, but they had started at a lower level. There was a steady increase in volatile fatty acids in all three trials.

Studies have been conducted by Lambert (32) and Allen (1) directed at determining the relationship of fat to the development of the rumen. Both have found the fat level in the blood to be relatively constant and only

present in traces at the 1-week age. As the feed intake increased, fat increased to about 168 mg. per 100 ml. of blood at 4 weeks of age. The fat content also was found to vary with the amount of fat in the feed.

Waldo and Schultz (56) conducted a series of studies aimed at determining the occurrence of lactic acid in the rumen, and its value as criteria for normal adult-type rumen function. Two groups of fistulated Holstein steers were used. One group was normally fed, while the second group was fed different carbohydrate supplements. No lactic acid was found in the normally fed group before feeding, but it rose to a peak at 1 hour after feeding. Lactic acid declined rapidly to prefeeding levels on all rations. Silage gave the highest concentrations, probably because much acid was introduced. Grain caused a higher level of lactic acid than did hay alone. Glucose was the only carbohydrate that produced lactic acid in the group of fistulated steers.

Rumen contents were analyzed for acid production in a study by Lengeman and Allen (34) as a measurement of the maturity of the rumen. At least five animals were sampled from each of the following age groups: 1 month, 1 to 2 months, 2 to 3 months, 5 to 6 months, 10 to 12 months, and cows over 2 years (milking). The chromatographic method was used in the determinations. No significant difference

was found between groups in amounts of propionic and butyric acid. Acetic acid was significantly lower in the 1-month-old group than in the others. The 1-month-old group also showed greater amounts of succinic acid and lactic acid fractions. According to these criteria no difference was noted among animals over 6 months of age.

McCarthy and Kesler (38) have made one of the latest studies concerning rumen development in which rumen juice samples were taken every 7 days from a group of calves. The experiment was ended when the calves reached 105 days of age. They found that volatile fatty acids in rumen juice increased from 156 mg. per 100 ml. at 7 days to about 600 mg. per 100 ml. at 63 days, which was maintained for the remainder of the experiment. Cellulose digestion, which was determined in the artificial rumen, increased steadily from 48.6% at 7 days of age to 87.1% at 105 days of age.

Eight female and four male grade calves were used by Wise, Peterson, and Gullickson (60) to study the effect of a no roughage diet on blood composition. The ration consisted of fresh raw milk fed twice daily and a grain ration and pasture ad libitum. Water was restricted; however, in order to increase the desire for milk. Blood plasma was analyzed for calcium, inorganic phosporous, magnesium, and fat. Whole blood was analyzed for

corpuscular plasma volume, hemoglobin, and sugar. The analysis was a weekly procedure. Restriction to a whole milk diet was found to cause anorexia, nervousness, and digestive disturbances. Blood analyses showed high blood sugar, extremes of fat in the plasma, a decrease in hemoglobin, and a gradual downward trend of magnesium in the plasma.

Bacterial changes due to rumen development. The rumen depends largely upon bacterial action for digestion and vitamin synthesis. Pounden and Hibbs (47) have observed four general microflora types in mature rumen contents. These types were large coccoids, large cigar shaped rods, small rods in flat rectangular groups and large thick square ended rods. These workers raised a Jersey calf to 6 months of age with a rumen free of protozoa, but containing large masses of cigar shaped rods. It had a neat, healthy appearance like 12 similar calves which received rumen inoculations, and were fed similar feeds. Three other calves whose rumens were devoid of the usual protozoa and the three rods, but contained large coccoids, had rough hair coats, and their abdomens appeared abnormally deep and pot bellied.

Rumen samples from about 100 adult cows and 100 calves in seven herds and 150 sheep from four flocks located in various parts of Ohio, New York, and Tennessee

were studied by Gall and Huhtanen (16) with respect to kinds and numbers of bacteria present. Results were obtained from over 5,000 isolations. From the data obtained five criteria were set up for judging true rumen organisms. The criteria were anaerobiosis, presence in numbers of at least 1,000,000 per g. of fresh rumen contents, isolation of similar types ten or more times from more than two different cows, isolation of similar types from two or more geographic locations, and the production by organisms of end products from substrates found in the rumen.

A proper pH is obviously needed in the digestive tract for optimum bacterial conditions. Monroe and Perkins (42) studied rumen samples from 16 cows and steers fitted with permanent rumen fistulae. When mixed hay was fed, the pH was 7.01; hay and corn silage, 6.95; bluegrass pasture, 6.47; and alfalfa pasture, 6.66.

Two hundred calves from three states and 200 adult cattle from eight locations were used in obtaining rumen flora data by Huhtanen, Saunders, and Gall (28). Calf rumens were consistently found to contain nine organisms not usually found in adult rumens. Eleven organisms characteristic to adult rumen were found in calf rumens as early as 2 months of age, and were found to increase in numbers as the animal aged. Organisms commonly found in calf rumens were fast-growing, lactic acid-forming

bacteria, which produced a low pH and heavy turbidity. Adult organisms grew more slowly with higher pH and little turbidity. Only two types of bacteria were found in the rumens of animals of all ages. More than two organisms have been commonly found in ruminants of all ages by other workers (16, 46, 47) as explained previously.

Contents of rumens of three inoculated and three uninoculated isolated calves were studied by Bryant and Small (7). Cultural methods and direct microscope examinations were used in the examinations. Many bacteria and protozoa were established in the inoculated group as early as 6 to 9 weeks of age. Few bacteria and none of the indicative protozoa were found in the inoculated calves even after 17 weeks of age. These workers concluded that inoculations will hasten protozoa development, but not bacterial development, unless calves are raised under isolated conditions.

The metabolism and physiology of rumen bacteria have been recognized by several workers as being directly concerned with the development of the rumen and the nutrition of the animal (10, 21, 40). The purpose of a study by McNeil, Doetsch, and Shaw (40) was to obtain information that would reveal the nature of the essentiality of rumen fluid to the rumen organisms. No materials were found which possessed the same stimulatory effect for the overall

rumen population as did rumen fluid. Rich nitrogenous materials ordinarily used for the growth of fastidious bacteria did not contain to any degree the essential factors found in rumen fluid. In fact many substances were found to be inhibitory. Rumen fluid was found to be a source of both nitrogen and growth factors when used in media for cultivating rumen bacteria.

Physiology of rumination. Rumination consists of the mechanical factors or phases of digestion. The phases are regurgitation, remastication, insalivation, and reswallowing. These four phases together with a slight pause after reswallowing, may be said to make up a "cycle of rumination" (12). The complex stomach, which is possessed by all ruminants, is a prerequisite of rumination, rather than the cause of rumination. Not all animals with complex stomachs ruminate (whale, hippopotamus, sloth) (5).

The graphic method was used by Bergman and Dukes (5) to analyze the act of regurgitation of the ox. The intrapulmonic changes of pressure during and between the act of regurgitation, movements of thoracic walls, movement of boluses in the neck, rumen pressure, and chewing movement were recorded on smoked paper by means of a pressure-operated recording tambour. Numerous direct observations also were made by means of a permanent fistula located in the left flank of the animal.

During the act of ruminating, a decided fall in intrapulmonic pressure was found. A negative pressure was experienced inside the esophagus as seen by a definite suction at the cardia at the time of regurgitation. From these and other observations several conclusions were made. In regurgitation in the ox, the entrance of food into the esophagus is effected by an aspiratory act of the thorax, the necessary negative pressure in the esophagus being produced by an inspiratory effort with a closed glottis. No definite bolus formation was noted. A fairly fluid condition is necessary for successful regurgitations. The rumen and abdominal muscles were not contracting at the moment of regurgitation. The esophageal groove appears to take no active part in regurgitation.

The study of the food bolus was undertaken by Schalk and Amadon (51) using the gastric fistula method. Both visual inspection and manual palpation were used in the studies of a cow with a permanent rumen fistula in the left flank. The rumen interior was illuminated by a small electric bulb supported by a three-foot length of stiff galvanized wire. The bolus, during the course of a meal, was projected into the stomach with considerable force and was rapidly deposited in the anterior rumen region.

The form, weight, and consistency of the bolus varied considerably, depending upon the type of food being

digested. Forage material such as green or cured hay was molded into a firm, oblong mass with rounded extremities. This type of bolus can be removed from the stomach immediately following its entrance, and will preserve its form even after extensive handling. Cured hay boli will float in water due to low moisture, but their weight rapidly increases after their arrival within the rumen due to absorption of the liquids in the rumen. Concentrate boli are much heavier than those composed of forage material due to higher density and more rapid moisture penetration. Ground feed forms a doughy bolus and quite often is dry in its center. The mean weight of hay boli was 85 g.; whole oats, 140 g.; ground grain feed, 101 g.; and whole corn, 81 g.

The bolus was deposited just within the cardia in the anterior part of the rumen. It was found that the reticulum undergoes two contractions following the entrance of one or sometimes several boli into the rumen. These contractions were closely spaced, the second being more powerful than the first. These contractions force flows of reticular ingesta posteriorly into the rumen cavity. These flows of liquid play an important part in transporting newly arrived food material away from the cardia region. Light-weight boli are obviously more easily moved posteriorly than are the heavy grain boli, thus hay boli are

usually stored in the depths of the rumen cavity. This movement is important to keep the space clear, which prevents any obstruction of the cardiac orifice. The rumino-reticular fold was found to be instrumental in directing the flows from the reticulum over the cardia region. These workers are in agreement with others (5, 15) in stating that much liquid is needed for efficient rumen operation.

Remastication is accompanied by reinsalivation. The remastication according to Fuller (15) was very slow and deliberate, differing markedly from the mastication of eating. This worker found, for example, that cows when eating grain and silage moved their jaws at an average of 94 times per minute and when eating hay, at an average rate of 78 per minute. When ruminating, the average rate of jaw movement was only 55 per minute. Ewing and Wright (14) found from a study of six 3-year-old Shorthorns that over 50% of the communition takes place during mastication. These animals were fed a ration of corn silage and cotton-seed meal. The analysis in this study was made from observations of organ contents after slaughter of the animals. In the case of incomplete mastication, communition was found to be adequately performed in the rumen and reticulum.

The ruminated bolus when swallowed, returns to the

rumen. It was formally believed that it passed down the esophageal groove to the omasum and abomasum (12). Direct examinations have proved that no food of any consequence passes along the groove in the ruminating animal (51).

Two factors concerning the removal of the freshly chewed bolus from the region of the cardia, so it will not be regurgitated a second time, were also observed by Shalk and Amadon (51). One factor is the high specific gravity, due to added saliva and stomach fluids, which causes the boli to tend to move down and posteriorly. The second, as stated previously, is the contractions of the reticulum.

Some observations of cattle activities. Most of the studies concerned with the activities or behavior of cattle deal with specific problems of dairy herd management. The most prevalent problem studied is grazing management. Few studies included quantitative work involving activities of cows for any substantial length of time.

Hancock (19) has offered some definitions of observation nomenclature. Ruminating time would include the total time spent in the cycle of rumination (both standing and lying) including the short time interval between cycles. Loafing time consists of time spent milling around while not grazing or lying. Resting time comprises that portion of lying time which is not occupied by rumination. Lying time would consist of resting or rumination while lying.

The purpose of many studies of cattle habits has been to learn more about the requirements and preferences under conditions prevailing by recording the time engaged in different activities. Cory (11) studied cattle, sheep, and goats under range conditions in Texas during daylight hours. He found that cattle spend 10% of the day traveling (3.3 miles). Fifty six percent of the day was spent feeding. Time spent drinking, 2.4 minutes; lying down, 102 minutes; and ruminating, 76 minutes. Grazing constituted 75% of the feeding time.

Atkeson, Shaw, and Cave (2) and Hancock (18) have conducted similar studies concerned with the effect of pasture quality on the activities of cattle, including rumination. Two cows were observed for grazing time on good, mixed (fair), and poor pastures by Atkeson and his associates. They found that more time was spent in grazing on poor pasture than on good pastures. Grazing time on poor pasture was 47% of daylight hours; fair pasture, 56% of the total time; and poor pasture, 62% of total time. The average daylight length during the study was 11.7 hours. Hancock studied the effect of pasture quality on grazing time and ruminating time. Good pasture was described as having evenly low fiber content; poor pasture, evenly high fiber content; and fair or mixed, varying fiber content. When large quantities of forage were available,

good quality pasture resulted in medium grazing time and short ruminating time. Mixed quality pasture resulted in long grazing time and long ruminating time. Poor pasture resulted in short grazing and long ruminating time. When low quantities of pasture were grazed, good quality pasture resulted in long grazing time and short ruminating time. Mixed and poor quality pasture caused long grazing time and medium ruminating time.

Three bullocks were used in a study by Hughes and Reid (27) in the summer of 1948, and eight bullocks were used in the summer of 1949. The study was concerned with time spent grazing, ruminating, and idling constantly on pasture. Observations were made monthly for 24 hours at 5-minute intervals. Grazing included short periods of walking to select herbage. Idling included time spent standing and lying down, when neither ruminating nor grazing. The average time for each activity was found to be:

1. Grazing - 7.9 hours
2. Ruminating - 7.3 hours
3. Idling - 9.3 hours

Grazing:ruminating time ratios were 2.05:1 in daylight, 0.08:1 at night and 1.12:1 for the overall 24-hour period.

Observations of behavior of four Shorthorn cows for a 24-hour period and of a herd of Shorthorns at monthly

intervals for a period of one year were made by Castle and Foot (8). The four cows were in a one-acre paddock. Night viewing was facilitated by the use of an infa-red "sniper-scope". Average grazing time was 6.25 hours; lying down, 9.22 hours; loafing (sum of above subtracted from 24 hours) 8.26; ruminating, 5.6 hours; defaecations and urinations, 11.6 and 9.8 times; number of drinks, 3.8; and distance walked, 3,060 yards. Herd observations were made at 5-minute intervals during the day and 15-minute intervals during the night. Stanchioned cows were very restless indicating that the out-of-doors was preferred.

Fuller (15) found no significant breed difference between Ayrshires, Guernseys, Holsteins, and Jerseys, as to standing and lying time during a 24-hour period. Time spent eating was 2.8 hours for Holsteins, 6.1 hours for Jerseys, and 5.98 hours for Guernseys and Ayrshires. Ruminating time for Holsteins was 8.98 hours; Jerseys, 8.8 hours; and Guernseys and Ayrshires, 8.1 hours.

Hancock (20) found in a cattle behavior study using 10 sets of identical twins, that climate was unimportant in causing the variation in time spent on the various activities. Quality and quantity of forage (external) was found to be very important in regulating cattle activities. Grazing time increased with scarcity of forage while ruminating time was increased by poor quality grass. Feed requirement

for milk production was found to be the most important factor (internal) determining variations in lengths of grazing and ruminating time. A characteristic rate of rumination and grazing was found between twins within a set.

EXPERIMENTAL PROCEDURE

Studies designed to gain more understanding about rumen development in young calves were conducted in the dairy calf herd of the University of Tennessee. Procedures that were used are explained below.

Feeding and management of calves. Calves were assigned to the studies as they became available from the University dairy herd. A total of 76 calves was used in one or more of the three phases of the study. The calves were purebred Holstein-Friesian and Jerseys, and grade Jerseys and Guernseys. The calves were left with their dams for 2 days. On the second or third day the calves were usually moved to individual pens in the calf barn. The milk ration was fed twice daily at 5:00 to 6:00 A.M. and P.M. For the first 6 days colostrum and whole milk were fed at 10% of body weight daily. Reconstituted skim milk was mixed with whole milk on the seventh day, and on the eighth day the milk was solely reconstituted skim milk.

The dry milk solids were fortified with 4,000 units of vitamin A, 500 units of vitamin D, and 50 mg. of aureomycin per pound. The milk was increased daily according to the expected gain of normal calves of each breed, so that the allowance was about 10% of body weight at all times. The Jerseys were weaned at 100 lb.,

crossbreds at 120 lb., and Holsteins at 150 lb. body weight. Mixed grass and legume hay was fed ad libitum from the time the calves were put in individual pens. Pelleted calf starter was fed up to a maximum of 4 lb. daily. Water was changed daily and was available at all times.

Pens were bedded with oat or wheat straw at first, followed by applications of wood shavings as often as necessary to maintain clean, dry conditions. The pens were 4 ft. by 12 ft. in size. Calves remained in these pens throughout the study.

Observations of daily activities. Twenty-eight normal calves (16 Holsteins and 12 Jerseys) were used in this phase of the study. Observations started on October 11, 1956 and ended on April 12, 1957. Each calf was observed from 6 to 112 days of age. The calves were observed every 2 weeks during a 24-hour period. The 24-hour periods were divided into four 6-hour shifts, which actually covered parts of 3 consecutive days. Observations of each calf were made at 5-minute intervals during the 24-hour period, and the activities of ruminating, eating and drinking, standing, and lying were checked.

The following definitions are applicable to the observed activities:

1. Ruminating time included the complete cycle of

rumination, including regurgitation, remastication, and swallowing, and the short interval between cycles.

2. Eating and drinking included the time spent taking food or water into the mouth, chewing, and swallowing.
3. Standing (self explanatory)
4. Lying (self explanatory)

The recording of data was facilitated by tally sheets, which were divided into 72 intervals for each of the four activities. Every 5 minutes the calves were observed and the appropriate column was checked. The time required to observe all the calves in each interval was about 2 minutes. One row of lights was used at night. This provided just enough light for the observations, yet did not disturb the calves.

Calf ages in days for the eight periods each calf was observed were; Period 1, 6 to 14; Period 2, 20 to 28; Period 3, 34 to 42; Period 4, 48 to 56; Period 5, 62 to 70; Period 6, 76 to 84; Period 7, 90 to 98; and Period 8, 104 to 112.

Blood glucose determinations. Blood from 16 Jersey and 16 Holstein calves was analyzed for glucose. Some of these calves were not used in the 24-hour observation studies. A total of 194 determinations was made. The

blood was analyzed once a week, starting with calves 1 week of age and younger for Period 1 and continuing through calves 15 to 16 weeks of age (Period 16). No attempt was made to compare seasonal differences. However, it should be noted that the determinations were made in late winter and early spring.

About 10 ml. of blood were collected from the jugular vein of the calves into a test tube containing 0.05 cc. of heparin solution, which was used as the anticoagulant. The blood was collected at noon, about 6 hours after the morning feeding. Analysis was made the same day as collection to minimize the effect of bacterial action.

The method of analysis used in the study was first developed by Somogyi (53) in 1945. This method was altered by using the new Somogyi (54) copper reagent and the arsenomolybdate color reagent developed by Nelson (44) for use with the Somogyi method. The samples were read in an Evelyn colorimeter using a 515 mμ filter rather than the 520 mμ filter suggested by Somogyi (53). The density of each transmission value was read from the colorimeter chart. A standard glucose solution containing 40 mg. % was analyzed with each group of blood samples. Blood glucose was calculated by using the following formula:

$$\text{Blood Glucose}_{(\text{Mg. \%})} = 40 \times \frac{1}{\text{Density of Standard}} \times \text{Density of Sample}$$

Collection of post-mortem specimens. Seventeen grade Jersey calves were sacrificed for observations of the digestive tract at about 2 weeks of age. These calves were fed milk or reconstituted skim milk for at least 3 days before sacrificing. On the day of sacrificing, the calves were fed 2.0 kg. of the usual experimental milk by nipple pail at the normal feeding time and were killed 2 hours later. In order to prevent regurgitation or mixing of the contents of separate organs, the calves were electrocuted. This was accomplished by attaching one electrode to the anus and another to the lip, and using a 110 volt current.

An incision was made posterior to the ribs, and the ribs were sawed off to expose the stomachs. Ties were made at the esophagus (cardia), at the omasal-abomasal junction, at the abomasal-duodenal junction, and at the separation of the ileum and jejunum. The digestive tract was then removed to the laboratory. Because of the difficulty of accurately separating their contents, the rumen, reticulum, and omasum were handled as one section. Nearly all the contents of this section were in the rumen-reticulum.

Age, weight, ration, and health notes were recorded for each calf. The rumen-reticulum-omasum and abomasum sections were weighed full and empty in order to get a

content weight and tissue weight. The pH of contents of these two sections and of the duodenum, jejunum, and ileum was determined by a Beckman Model G pH meter. A description of the digestive tract and its contents was also recorded.

Three of these calves were observed for the four activities in the manner explained previously for one 24-hour period before sacrificing.

RESULTS

Averages of observed activities. Fourteen Holstein calves in Periods 1 through 4 (6-14 days old through 48-56 days old) and 16 Holstein calves in Periods 5 through 8 (62-70 days old through 104-112 days old) were used in obtaining activity observations at 5-minute intervals for 24 hours every 2 weeks. Eleven Jersey calves in Periods 1 through 3 (6-14 days old through 34-42 days old) and 12 Jersey calves in Periods 4 through 8 (48-56 days old through 104-112 days old) were also used for these observations.

The average percentages of Holstein calves engaged in the observed activities (ruminating, eating and drinking, standing, and lying) for each period during the day and night hours are shown in Table II. The average percentage of calves ruminating was highest during the day hours through Period 2 (20-28 days old), but was an average of 3.2% higher during the night hours than the day hours from Period 3 (34-42 days old) through Period 8 (104-112 days old). The average percentage of calves eating and drinking was 3.6% higher during the day hours than during the night hours throughout the 112-day study. This situation was found in the average percentages of calves standing. An average of 7.8% more calves was standing

during the day hours than in the night hours. As shown in Table II, standing and lying percentages are exactly opposite.

The average percentage of Holstein calves ruminating during the day and night hours increased each period throughout the entire study. The average percentage of calves eating and drinking increased through Period 6 (76-84 days old), but decreased slightly in Period 7 (90-98 days old) and in Period 8 (104-112 days old). The average percentage of calves standing increased each period up to Period 7 (90-98 days old) and decreased in Period 8 (104-112 days old).

The averages of the observed activities for 14 Holstein calves in Periods 1 through 4 are shown in Figures 1 through 4. Little rumination was observed at feeding time, otherwise periods of rumination were uniform throughout the day. The percentage of calves standing was highest at feeding time. The minimum percentage of standing calves was noted at 11 to 12 o'clock both day and night. The percentage of calves eating and drinking was highest at feeding time in Periods 1 through 4.

The percentages of 16 Holstein calves that were ruminating at various times in Periods 5 through 8 were very similar as illustrated in Figures 5 through 8. The highest peaks came in the early morning before feeding.

TABLE II

AVERAGE PERCENTAGE OF HOLSTEIN CALVES OBSERVED RUMINATING, EATING AND DRINKING, STANDING, AND LYING AT 5-MINUTE INTERVALS DURING THE DAY AND NIGHT HOURS

Period	Age	Calves	Holstein Calves Observed							
			Ruminating		Eating and Drinking		Standing		Lying	
			Day	Night	Day	Night	Day	Night	Day	Night
	(Days)	(No.)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1	6-14	14	4.8	3.8	7.3	5.7	28.9	20.5	71.1	79.5
2	20-28	14	13.8	13.1	13.7	9.2	35.4	25.8	64.6	42.2
3	34-42	14	16.6	17.1	15.8	13.2	40.6	39.0	59.4	61.0
4	48-56	14	18.1	21.8	16.3	16.2	41.1	34.8	58.9	65.2
5	62-70	16	22.0	29.3	23.4	17.3	43.8	38.8	56.2	61.2
6	76-84	16	27.8	30.9	27.1	19.1	45.3	34.3	54.7	65.7
7	90-98	16	30.2	31.8	23.2	20.3	51.2	50.8	48.8	59.2
8	104-112	16	31.8	34.8	23.1	20.1	48.1	37.8	51.9	62.2

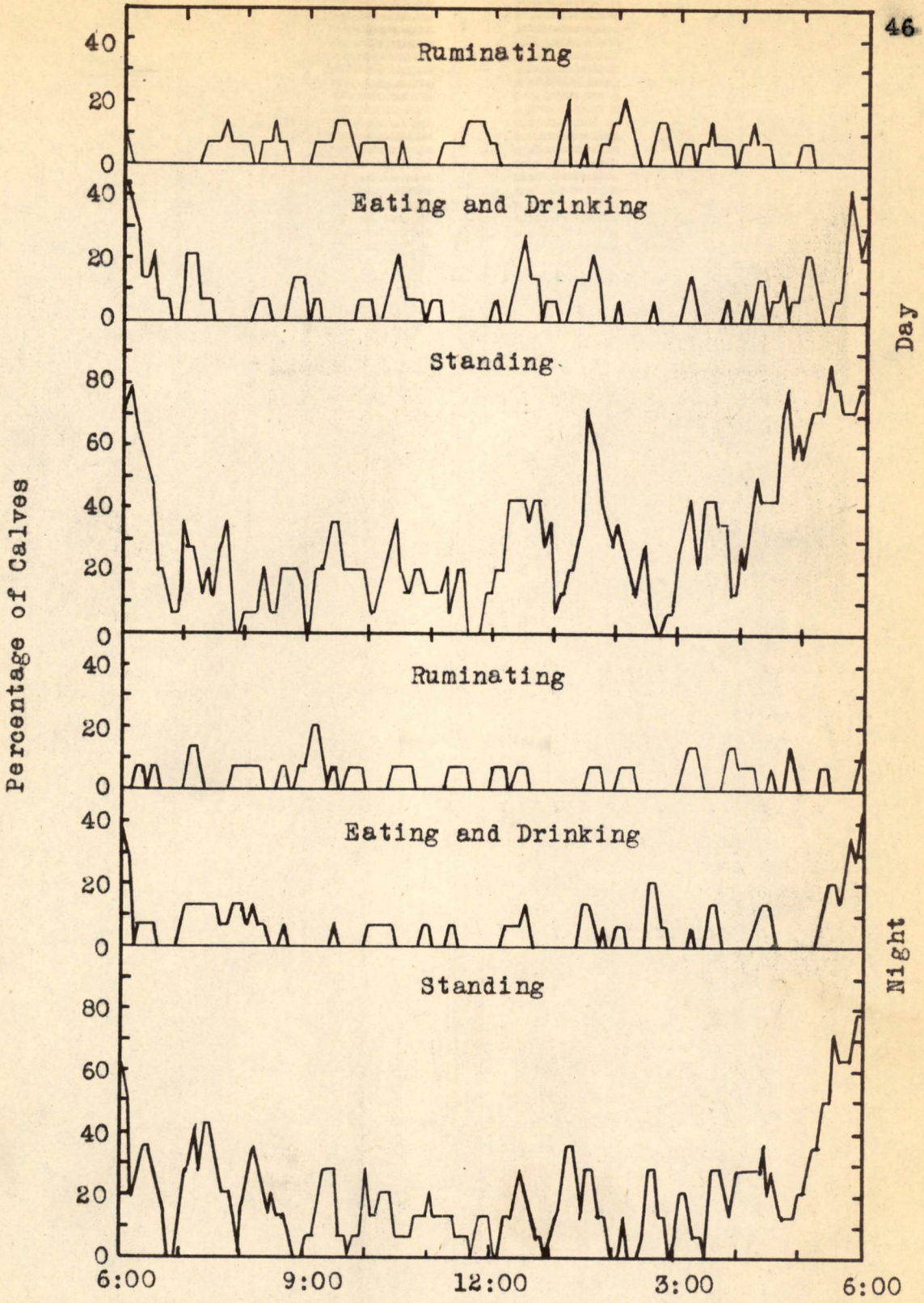

Fig. 1. Percentage of Holstein calves in Period 1 (6-14 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

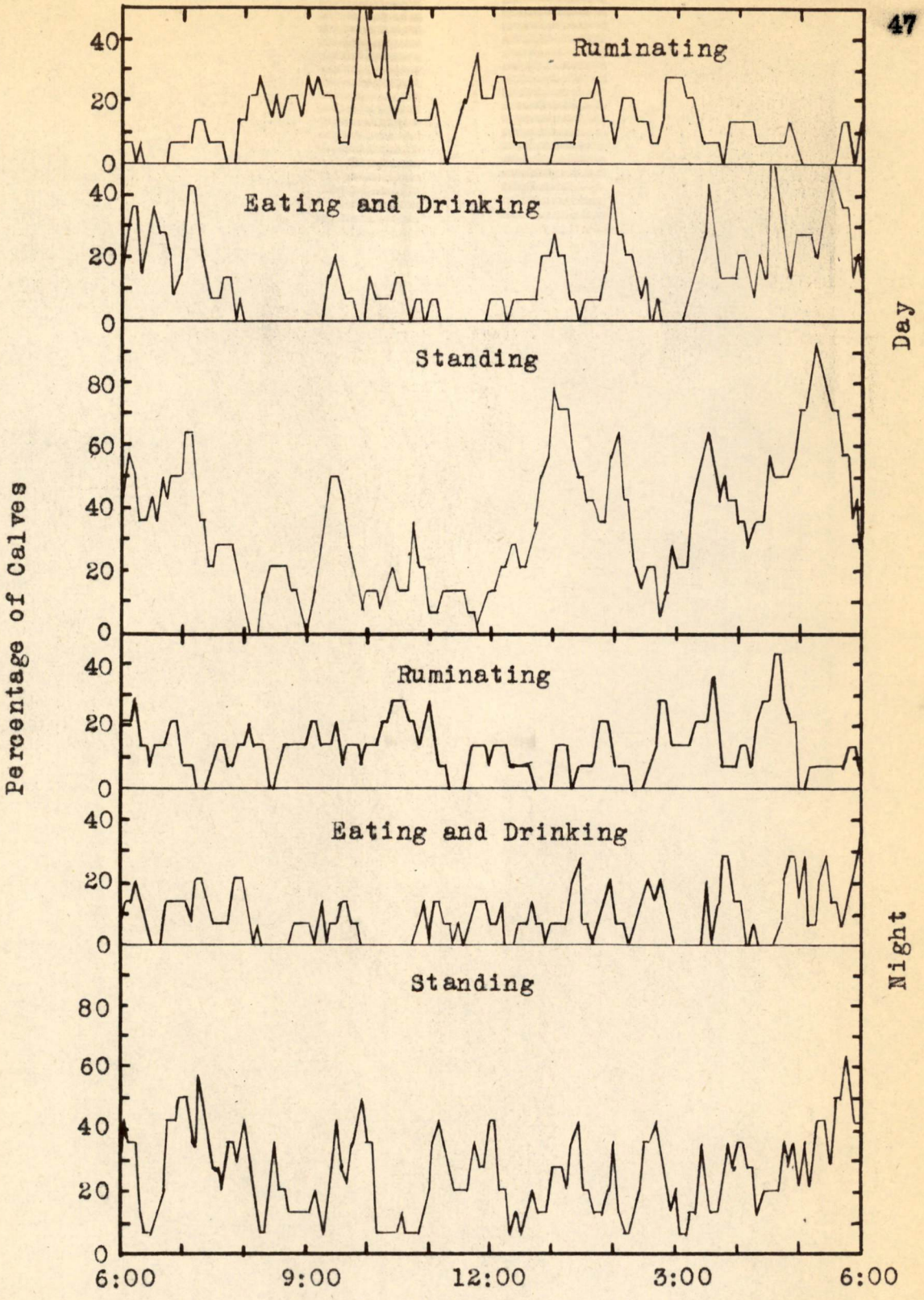

Fig. 2. Percentage of Holstein calves in Period 2 (20-28 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

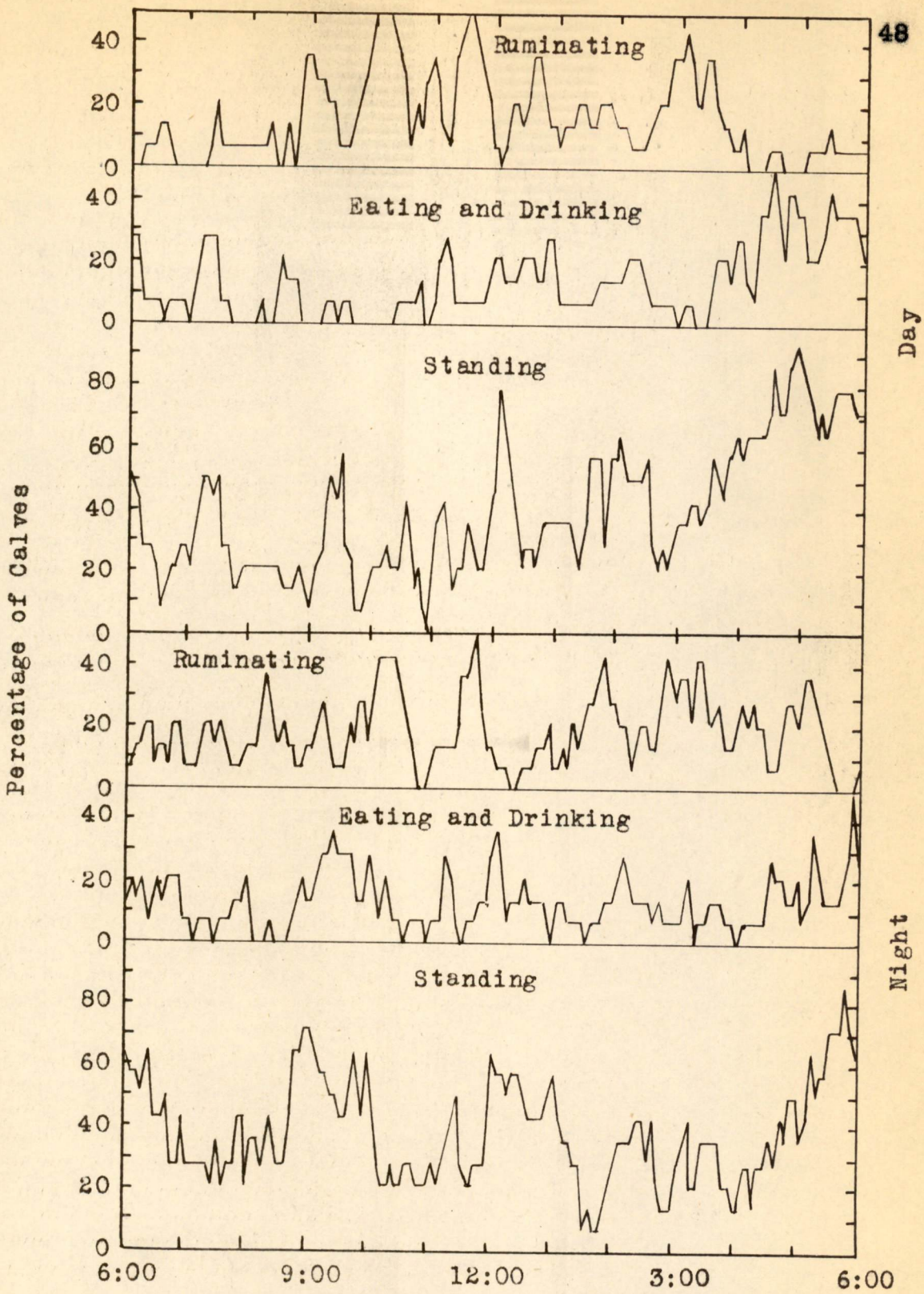

Fig. 3. Percentage of Holstein calves in Period 3 (34-42 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

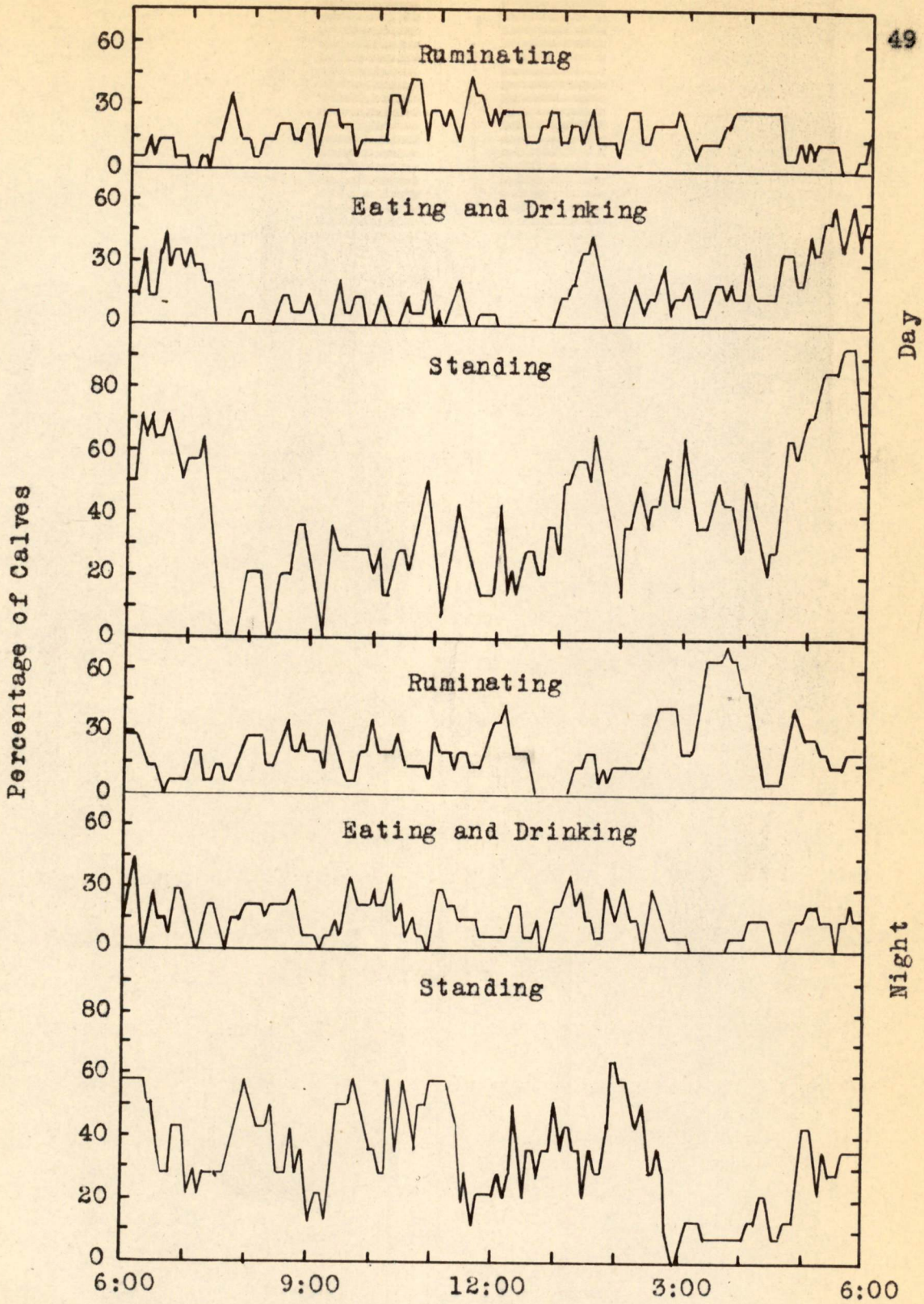

Fig. 4. Percentage of Holstein calves in Period 4 (48-56 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

During the remainder of the day generally uniform percentages of calves were ruminating except at feeding time when a drop occurred. It was also noted that a lower percentage was eating and drinking at mealtime than in the first four periods. This was probably due to the cessation of milk feeding. As in the first four periods, the percentage of calves standing was highest at feeding time and lowest at 11 to 12 o'clock both day and night. The percentage of calves standing varied less during the day in Periods 5 through 8 than in the first four periods, however.

The average percentages of Jersey calves ruminating, eating and drinking, standing, and lying for each period during the day and night hours are shown in Table III. The percentage of calves ruminating was highest during the daylight hours in Periods 1 (6-14 days old) and 3 (34-42 days old), and highest by an average of 3.5% during the night hours in Periods 2 (20-28 days old) and 4 through 8 (48-56 days old through 104-112 days old). There was an average of 5.4% more calves eating and drinking during the day than at night, and calves standing averaged 11.6% higher during the day than at night. The average percentage of Jersey calves ruminating increased from 2.5% in Period 1 to 20.7% in Period 4. A decrease in percentage to 17.9 was noted in Period 5. The percentage began to increase again in Period 6 to 24.2 in Period 8.

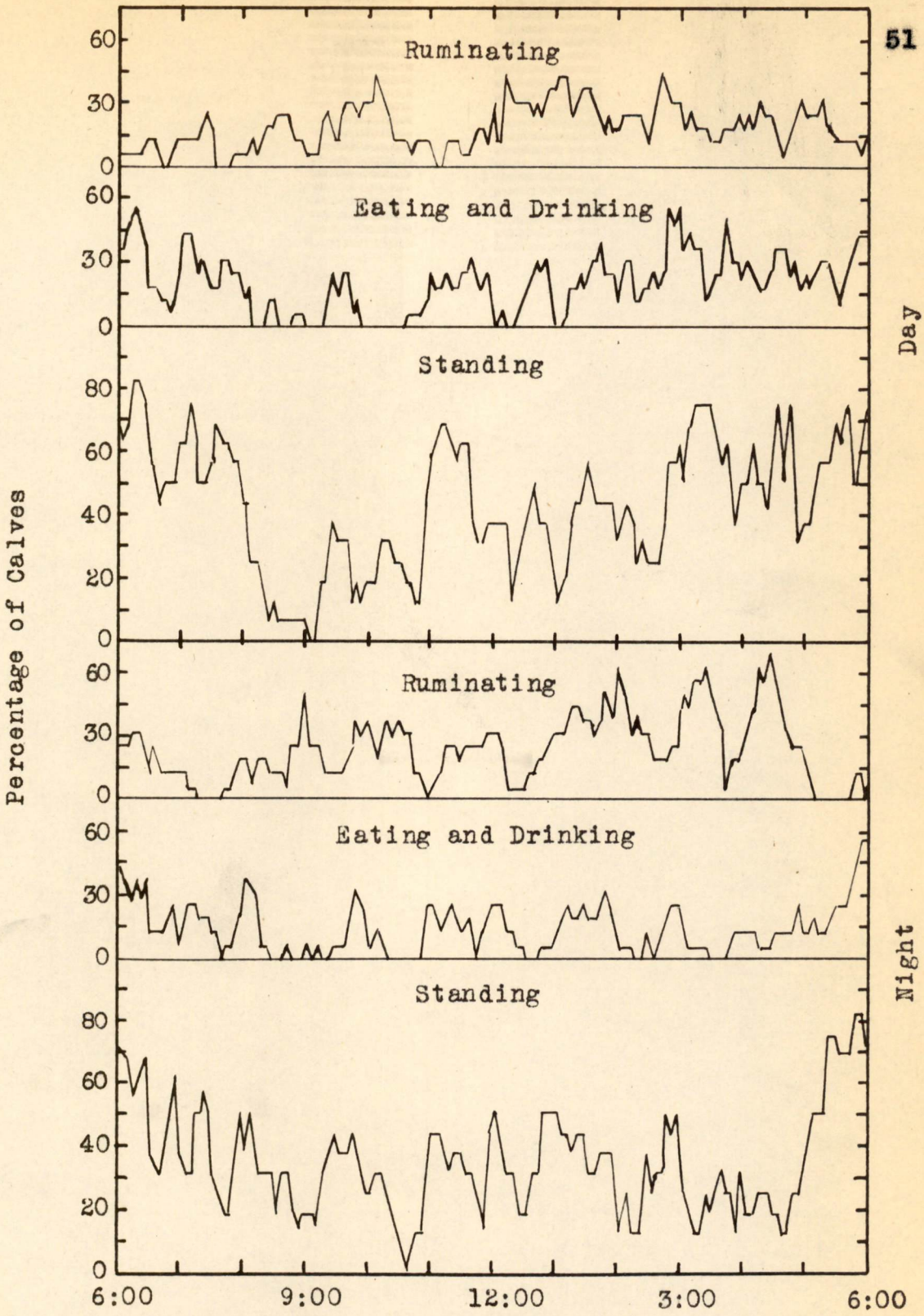

Fig. 5. Percentage of Holstein calves in Period 5 (62-70 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

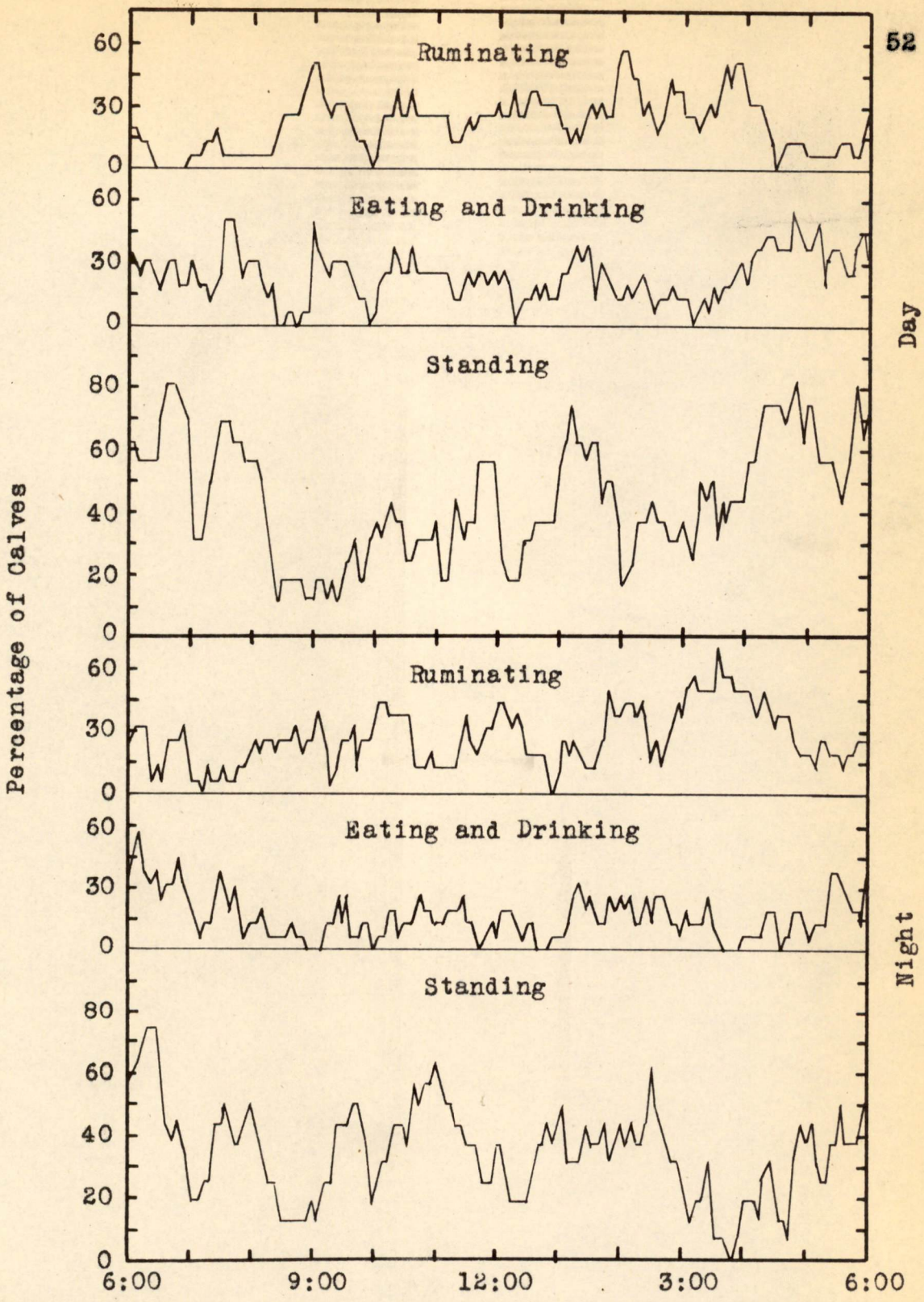

Fig. 6. Percentage of Holstein calves in Period 6 (76-84 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

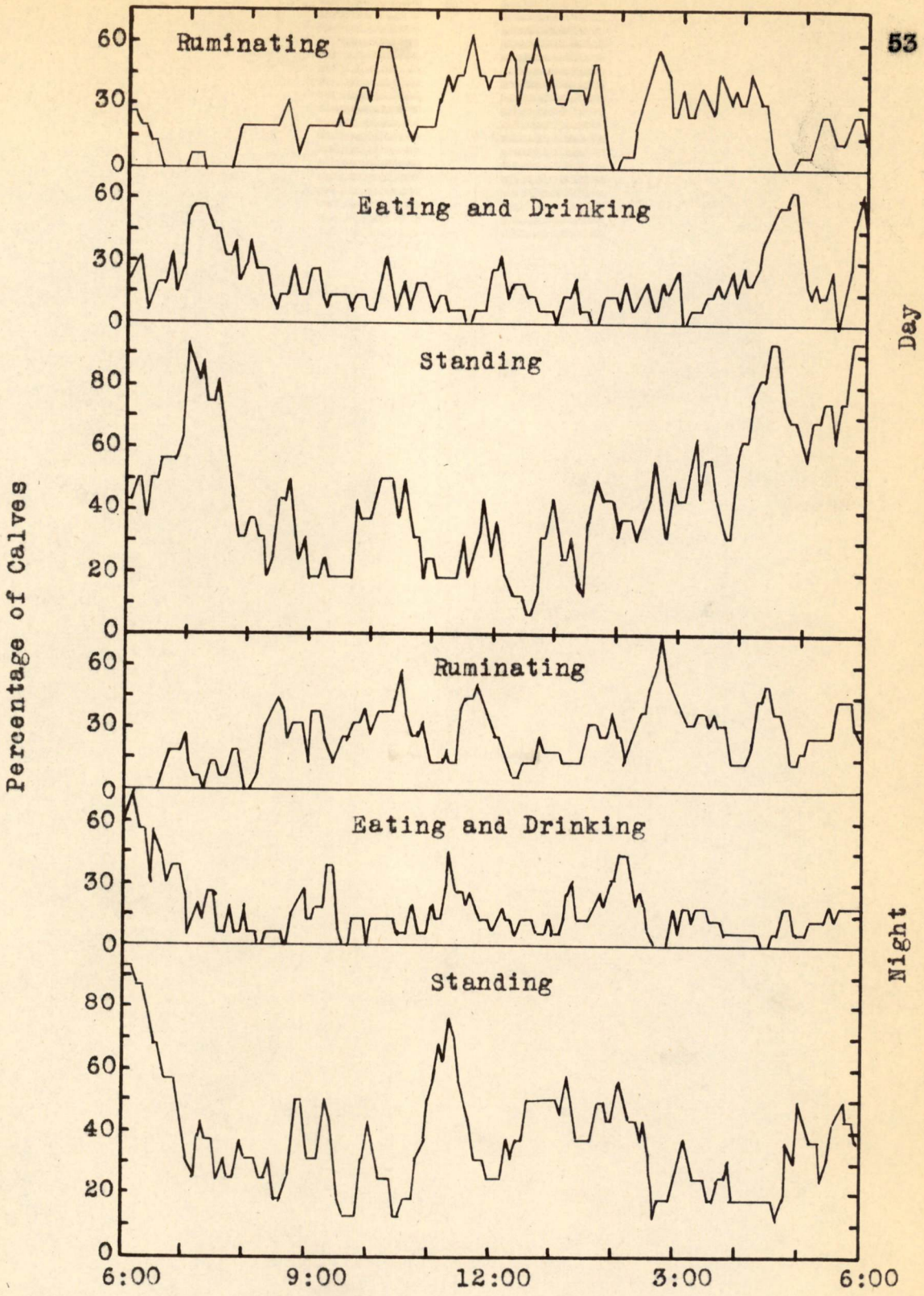

Fig. 7. Percentage of Holstein calves in Period 7 (90-98 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

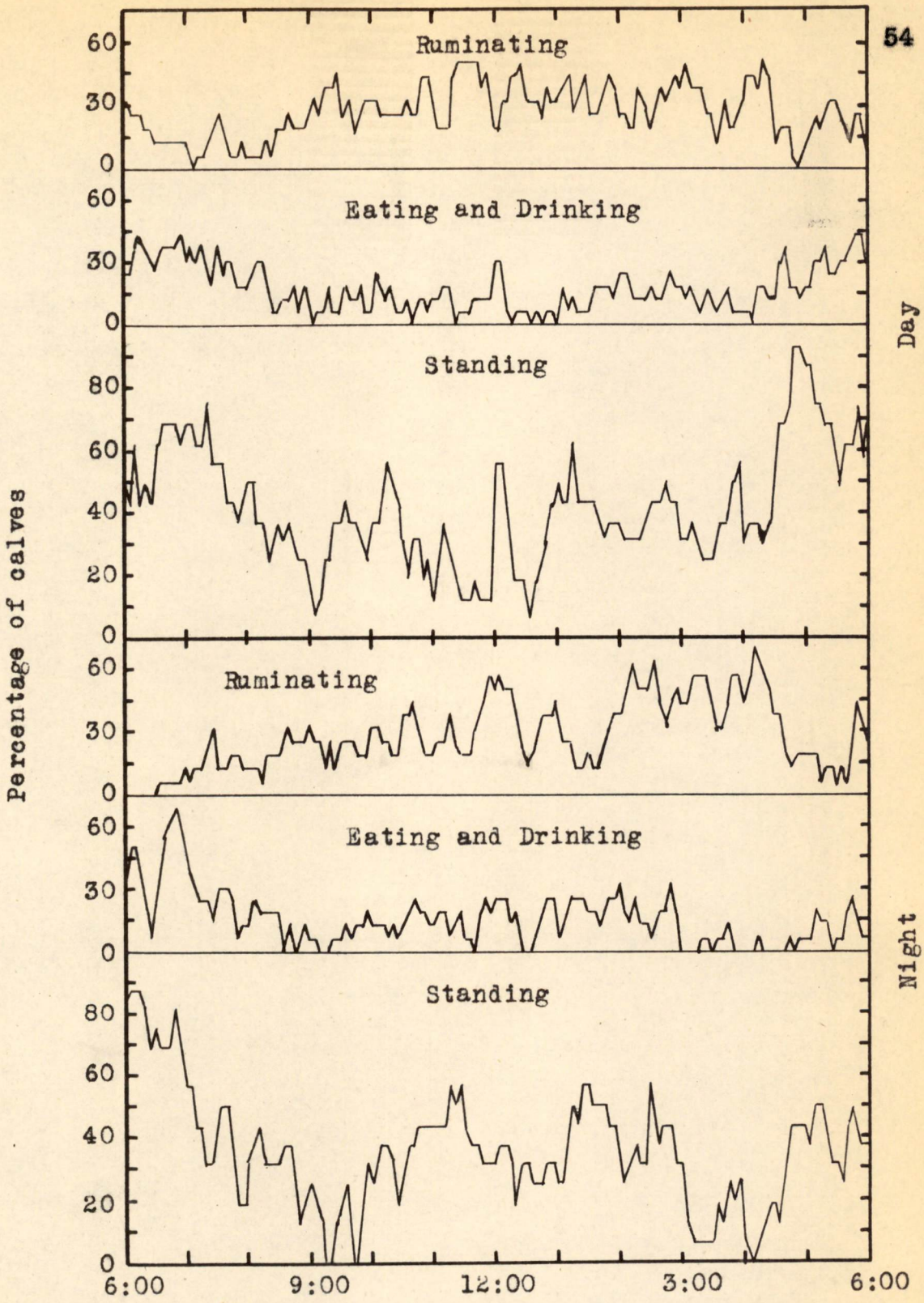

Fig. 8. Percentage of Holstein calves in Period 8 (104-112 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

The average percentage of Jersey calves eating and drinking at one time increased from 7.1 in Period 1 to 15.9 in Period 6. From this point the percentage decreased to 13.8 in Period 8. The percentage of calves standing increased steadily from Periods 1 through 7, and decreased slightly in Period 8.

As in the case of the Holsteins, the Jersey calves ruminated less at feeding time than the remainder of the day. The percentage of calves ruminating was fairly uniform throughout the day except at feeding time in Periods 1 through 8 (Figures 9 through 16).

The percentage of Jersey calves eating and drinking and standing tended to parallel each other in all periods with highest peaks being recorded during feeding time. These activities followed a pattern similar to that of the older Holstein calves in that more eating and drinking were being done throughout the day than in the younger age groups.

Development of rumination. The numbers and percentages of Holstein and Jersey calves that had started to ruminate in Periods 1, 2, and 3 are shown in Table IV. These periods cover calf ages of 6 to 42 days. All of the Holstein calves had started to ruminate by Period 2 (20-28 days old), and all Jerseys had started to ruminate by Period 3 (34-42 days old).

TABLE III

AVERAGE PERCENTAGE OF JERSEY CALVES OBSERVED RUMINATING, EATING AND DRINKING, STANDING, AND LYING AT 5-MINUTE INTERVALS DURING THE DAY AND NIGHT HOURS

Period	Age	Calves	Jersey Calves Observed							
			Ruminating		Eating and Drinking		Standing		Lying	
			Day	Night	Day	Night	Day	Night	Day	Night
	(Days)	(No.)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1	6-14	11	3.4	1.6	8.9	5.4	35.9	22.1	64.1	77.9
2	20-28	11	11.1	13.1	13.5	8.4	34.9	23.5	65.1	76.5
3	34-42	11	20.0	18.9	13.8	12.9	42.2	32.3	53.1	67.8
4	48-56	12	18.4	23.1	14.8	14.1	38.9	36.7	61.6	63.9
5	62-70	12	15.6	20.1	20.3	10.9	47.2	35.2	52.8	64.8
6	76-84	12	17.3	19.5	19.8	11.9	46.3	30.5	53.7	69.5
7	90-98	12	19.2	22.3	18.7	11.3	46.1	30.7	53.9	69.3
8	104-112	12	22.1	26.4	17.9	9.6	43.4	30.8	56.6	69.2

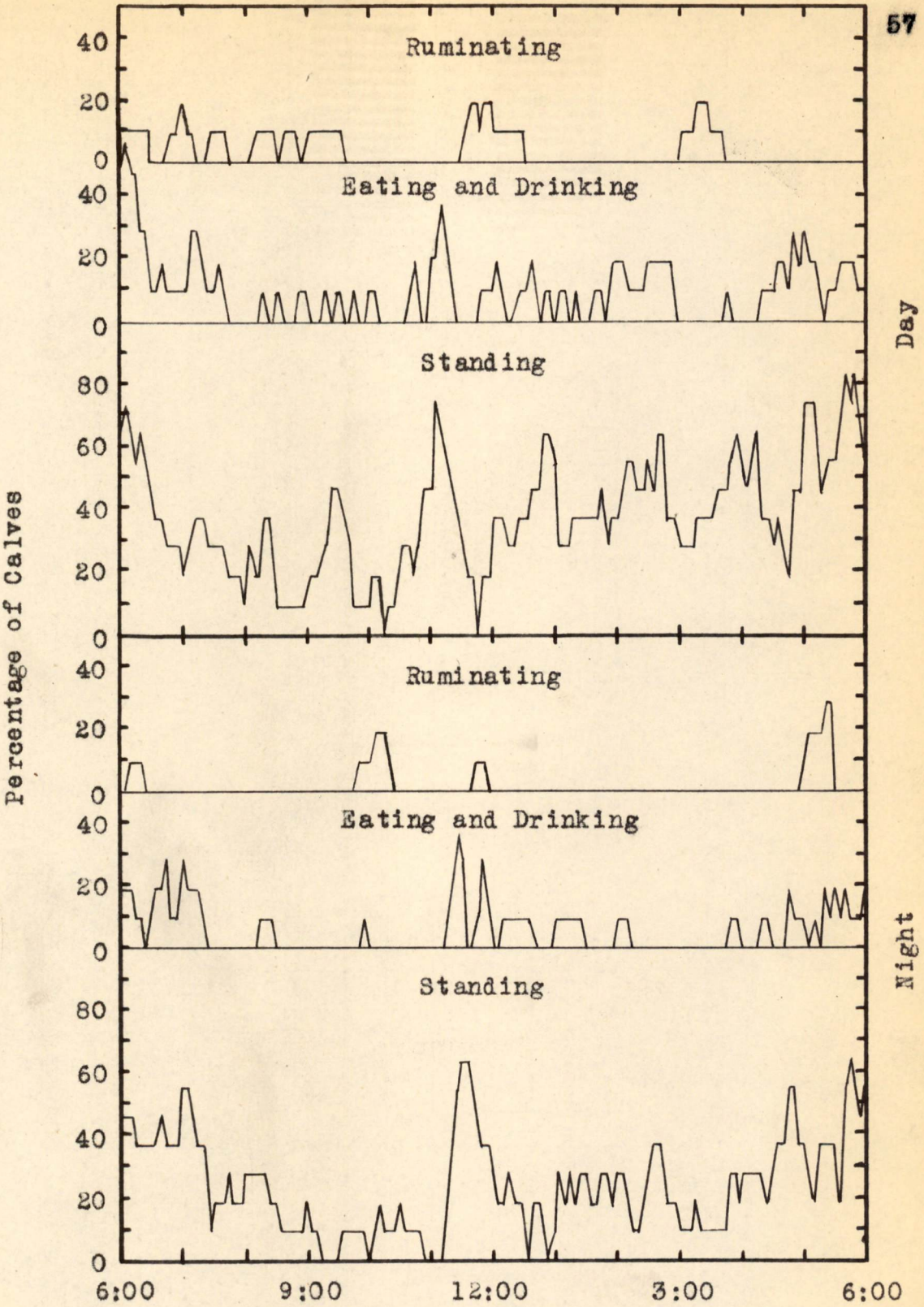

Fig. 9. Percentage of Jersey calves in Period 1 (6-14 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

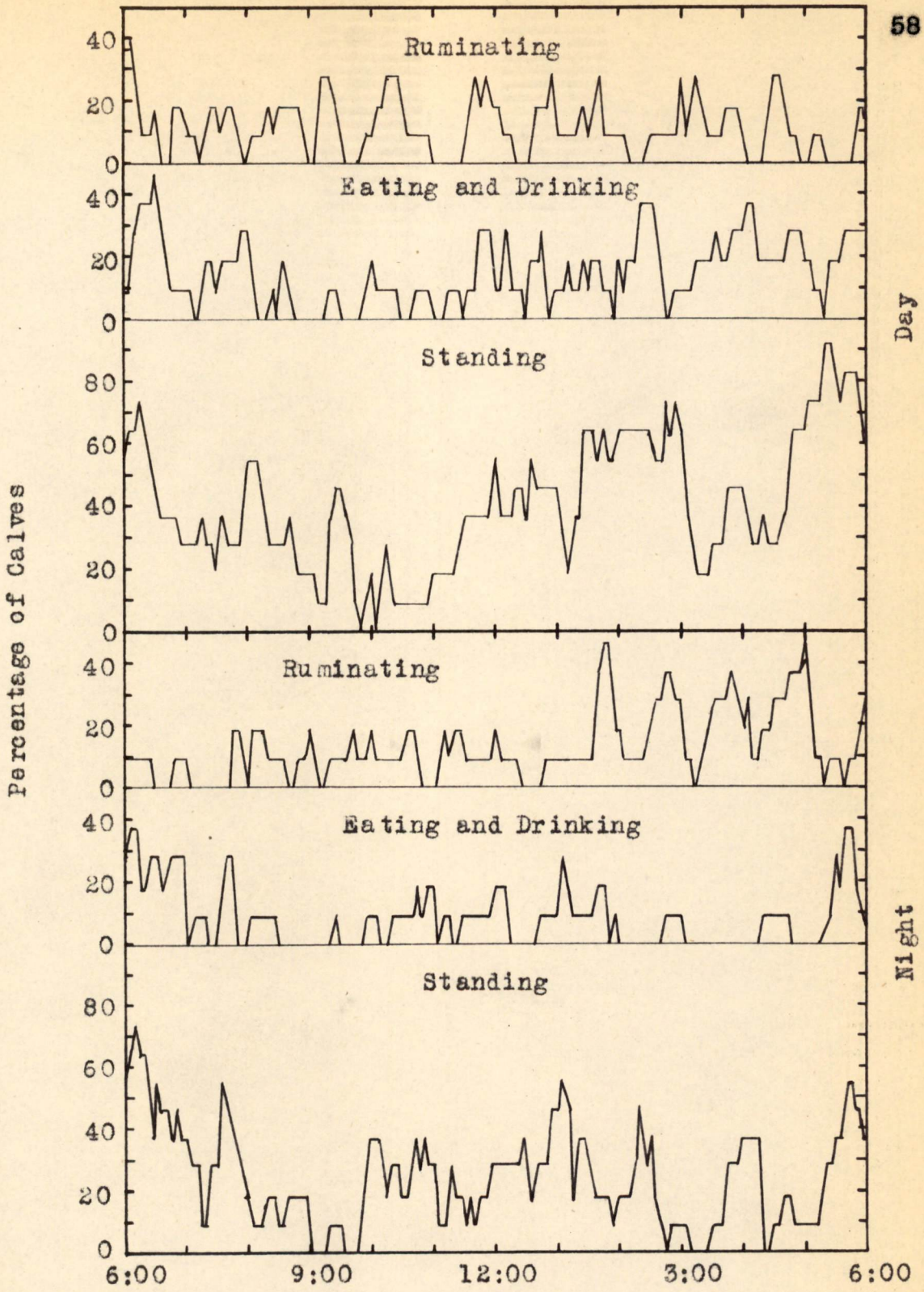

Fig. 10. Percentage of Jersey calves in Period 2 (20-28 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

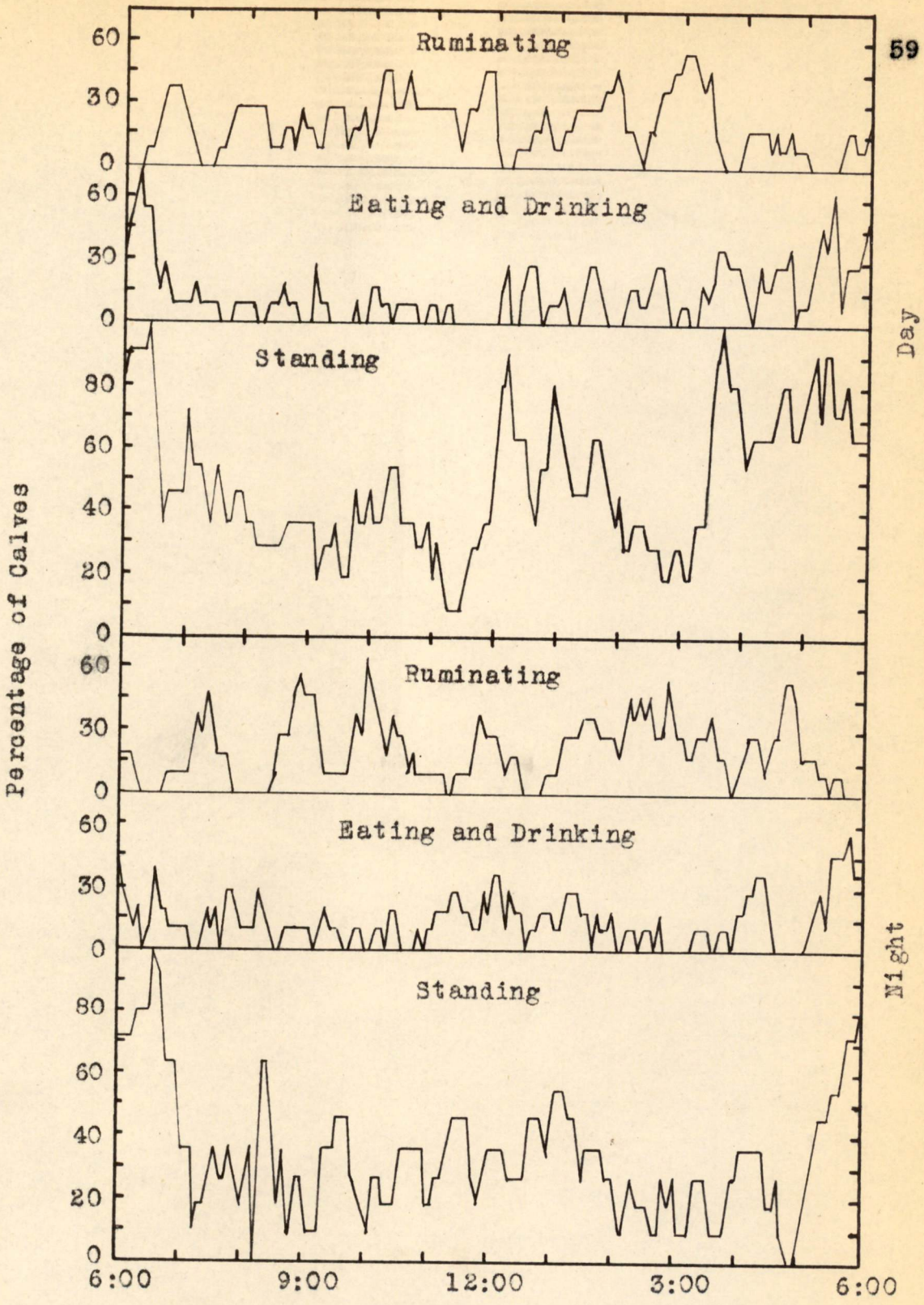

Fig. 11. Percentage of Jersey calves in Period 3 (34-42 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

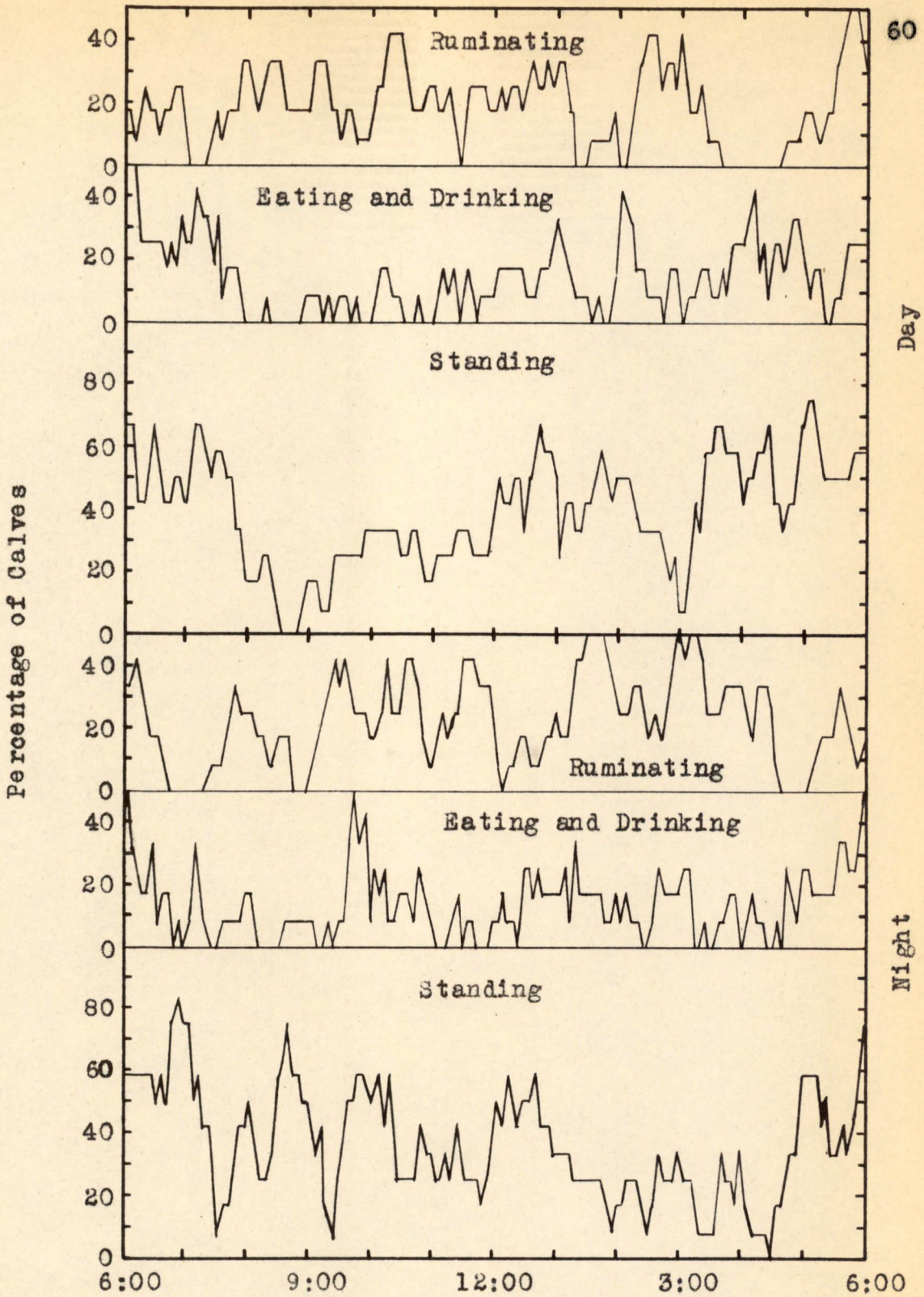

Fig. 12. Percentage of Jersey calves in Period 4 (48-56 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

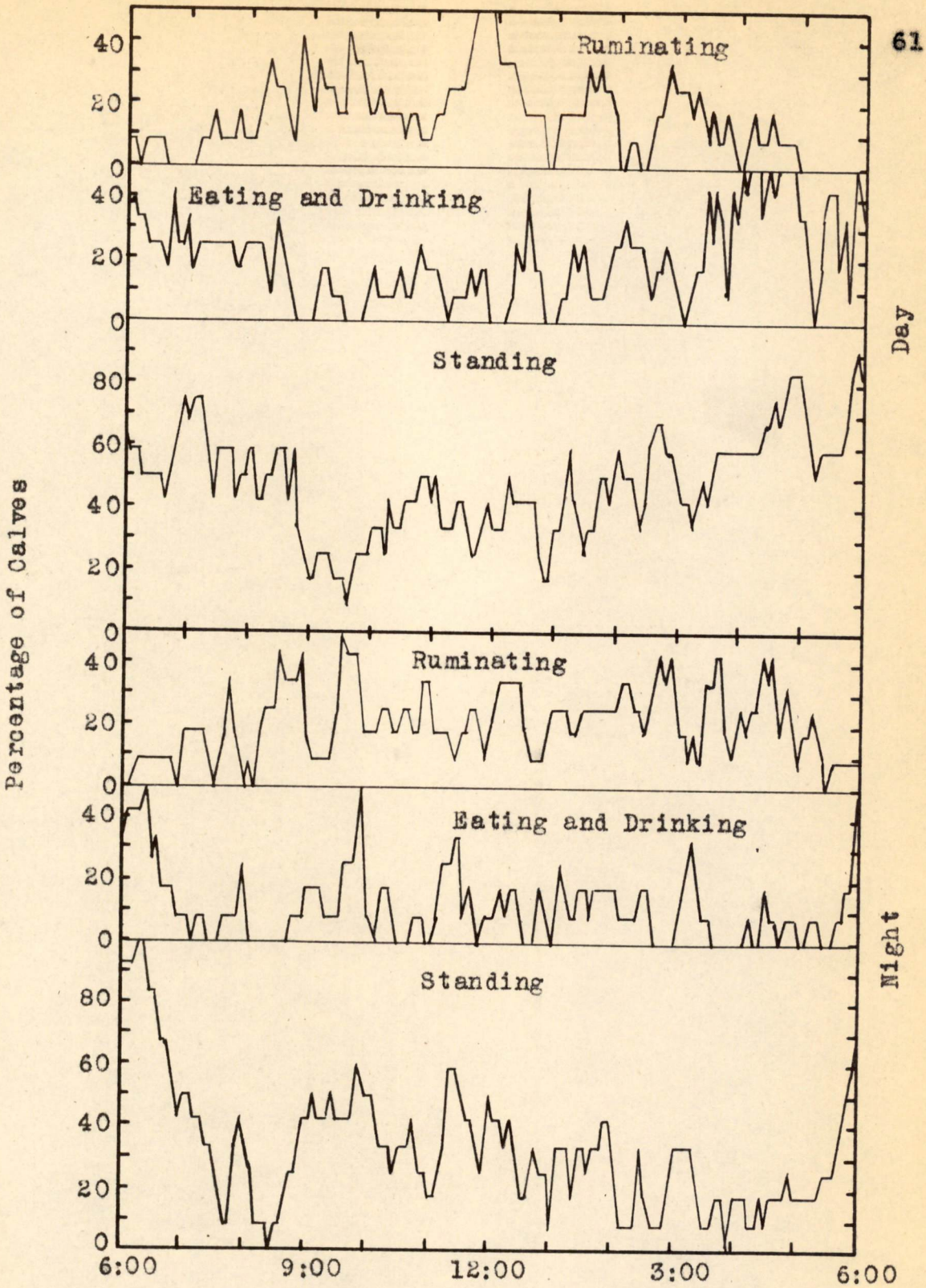

Fig. 13. Percentage of Jersey calves in Period 5 (62-70 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

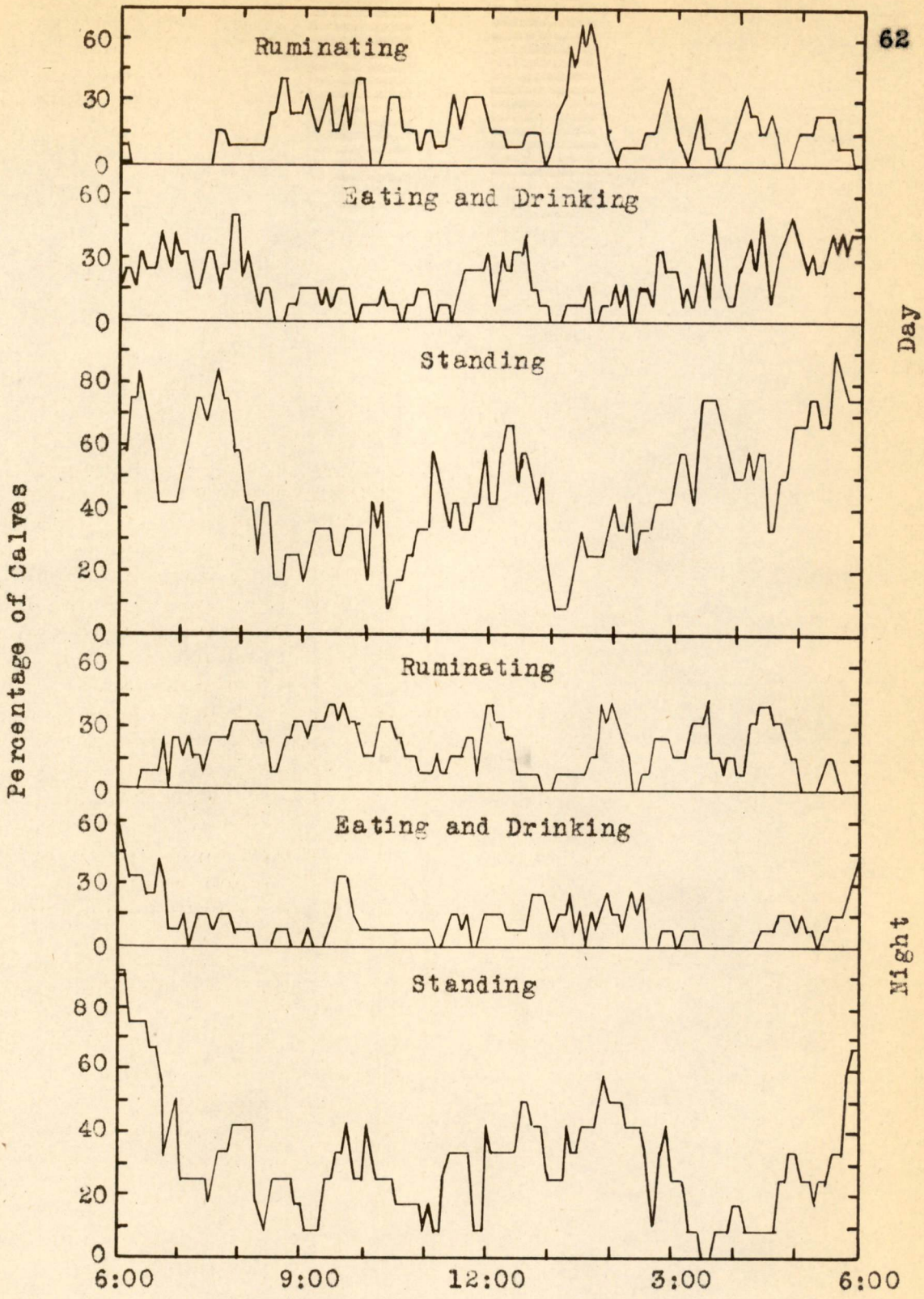

Fig. 14. Percentage of Jersey calves in Period 6 (76-84 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

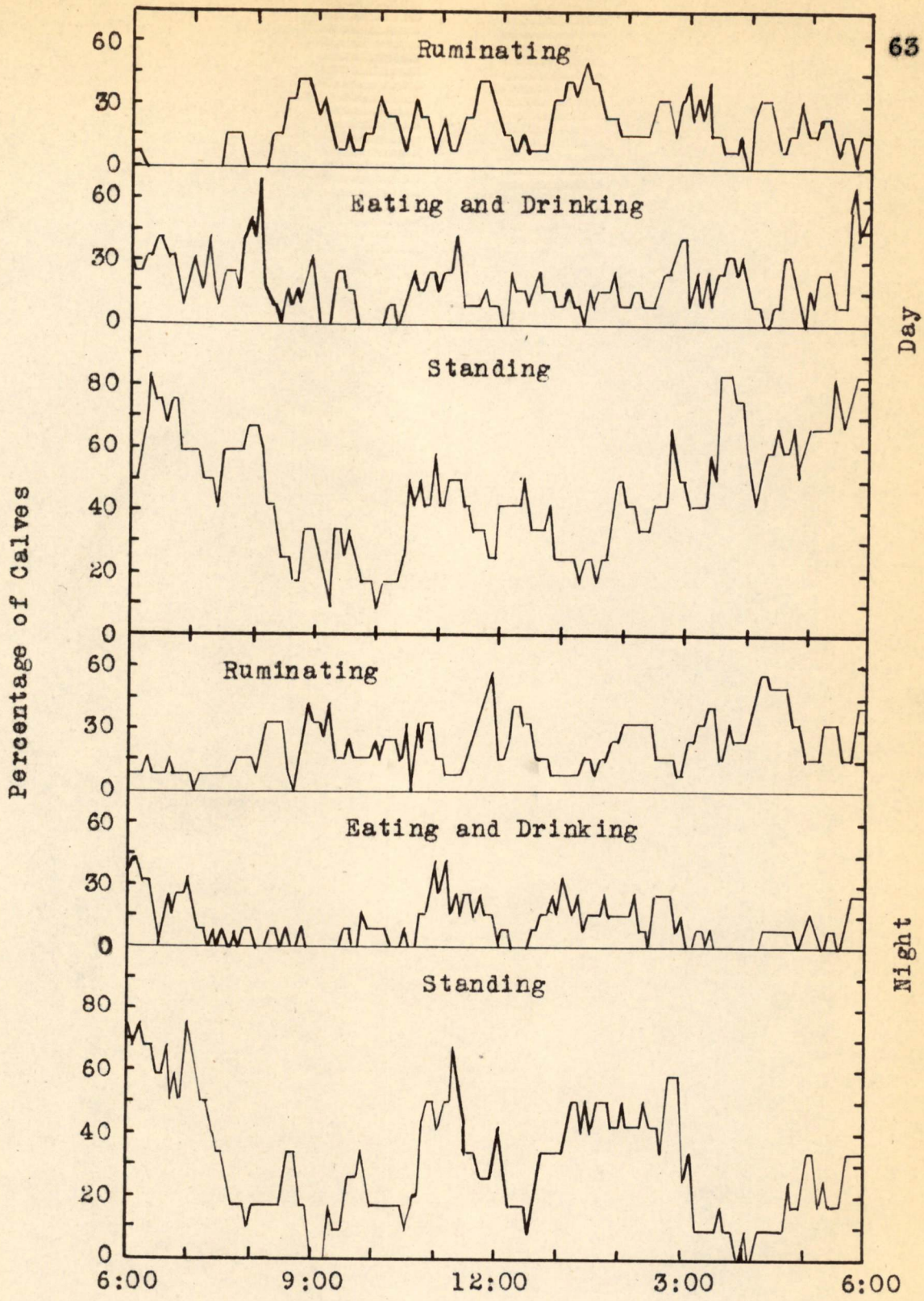

Fig. 15. Percentage of Jersey calves in Period 7 (90-98 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

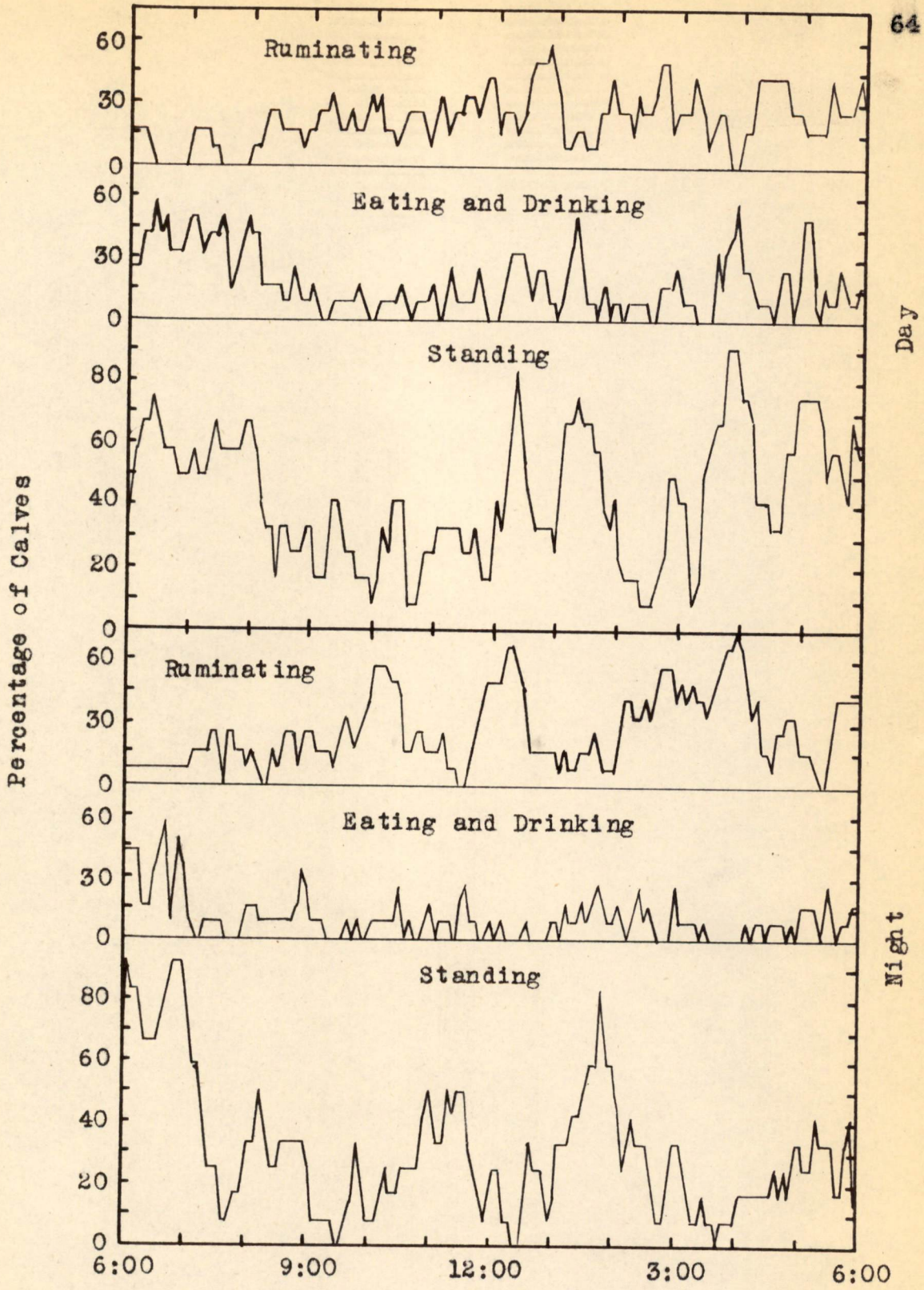

Fig. 16. Percentage of Jersey calves in Period 8 (104-112 days old) ruminating, eating and drinking, and standing observed for a 24-hour period.

TABLE IV

NUMBER AND PERCENTAGE OF HOLSTEIN AND JERSEY CALVES THAT RUMINATED, BY AGE GROUPS

Period	Age	Holsteins			Jerseys		
		Total	Ruminating		Total	Ruminating	
	(Days)	(No.)	(No.)	(%)	(No.)	(No.)	(%)
1	6-14	14	11	78.6	11	7	63.6
2	20-28	14	14	100.0	11	10	90.9
3	34-42	14	14	100.0	11	11	100.0

The youngest Jersey observed ruminating was 10 days old, and this calf ruminated for 45 minutes of the 24-hour period. The latest Jersey to start ruminating was observed in Period 3 (42 days old). This calf ruminated for 235 minutes in the 24-hour period, so apparently it had developed well in the 2 weeks since its last observation. Rumination was observed in the youngest Holstein at 7 days of age, and this calf ruminated for only 15 minutes in the 24-hour period. The latest Holstein to start ruminating was observed in Period 2. The age of this calf was 23 days, and it ruminated 310 minutes in the 24-hour period. It had apparently developed nearly normal rumination in the time between observations at 9 and 23 days of age.

The average time spent ruminating, eating and drinking, standing, and lying by Holstein and Jersey calves for 24 hours during each observation period is shown in Table V. The time ruminating by Holstein calves increased during each period from 63.6 minutes per 24 hours in Period 1 (6-14 days days old) to 376.4 minutes per 24 hours in Period 8 (104-112 days old). A slower rate of increase of time ruminating was noted after Period 4 (48-56 days old) than in the first three periods. The average rate of increase during the 2-week intervals between periods through Period 3 (34-42 days old) was 91.9 minutes per 24-hours per interval. This increase from Period 4 (48-56

days old) through Period 8 (104-112 days old) was 20.5 minutes per 24 hours per interval.

The time eating and drinking by Holsteins increased from 94.3 minutes in 24 hours in Period 1 (6-14 days old) to 265.3 minutes per 24 hours in Period 6 (76-84 days old), then decreased to 236.8 minutes per 24 hours in Period 8 (104-112 days old). The time standing paralleled this pattern rather closely, but was more than twice the time actually observed eating and drinking.

The time ruminating by Jersey calves increased from 32.3 minutes per 24 hours in Period 1 (6-14 days old) to 300.0 minutes per 24 hours in Period 3 (34-42 days old). The time ruminating observed during the next two periods decreased to 261.6 minutes per 24 hours in Period 5 (62-70 days old), then increased to 374.6 minutes per 24 hours in Period 8 (104-112 days old).

A slower rate of increase in time ruminating for Jerseys was noted after Period 4 (48-56 days old) than in the first three periods. The average rate of increase during the 2-week intervals between periods for the first three periods was 100 minutes per 24 hours per interval. The increase from Period 4 (48-56 days old) through Period 8 (104-112 days old) was 14.9 minutes per 24 hours per interval.

The time spent by the Jersey calves in eating and drinking and standing increased in parallel except for the

414.5 minutes standing per 24 hours in Period 1 (6-14 days old) which seemed abnormally high.

The time lying is exactly opposite to the time standing for both breeds.

The average number and length of times ruminating per 24 hours by Holstein and Jersey calves for each period are shown in Table VI. The average length of each ruminating time for Jerseys and Holsteins is very similar for all ages. There was a rather rapid increase from 13.3 minutes each time ruminating in Period 1 (6-14 days old) to 23.4 minutes in Period 3 (34-42 days old) for the Holsteins. Jersey calves averaged 12.9 minutes ruminating each time in Period 1 and 23.0 minutes in Period 3. The average length of the rumination times was relatively constant for the remainder of the observation periods.

The number of times per day ruminating was about the same for Holsteins and Jerseys throughout the experiment, except in Period 1, when the Holstein calves ruminated an average of 4.8 times per day, and Jerseys ruminated an average of 2.5 times per day. There was a gradual increase in number of times observed ruminating from 9 to 10 in Period 2 to 14 to 15 in Period 8. The increase in total rumination time, which occurred with age, was due more to an increased number of rumination periods than to longer periods.

TABLE V

AVERAGE TIME SPENT RUMINATING, EATING AND DRINKING, STANDING, AND LYING FOR 24 HOURS DURING EACH PERIOD FOR JERSEY AND HOLSTEIN CALVES

Period	Age	Holsteins				Jerseys			
		Rumina-ting	Eating & Drinking	Stand-ing	Lying	Rumina-ting	Eating & Drinking	Stand-ing	Lying
	(Days)	(Min.)	(Min.)	(Min.)	(Min.)	(Min.)	(Min.)	(Min.)	(Min.)
1	6-14	63.6	94.3	361.1	1078.9	32.3	103.6	414.5	1025.5
2	20-28	197.1	166.4	437.5	1002.5	176.8	155.0	412.7	1027.3
3	34-42	273.9	208.9	552.5	887.5	300.0	185.0	546.4	893.6
4	48-56	288.5	217.5	518.2	921.8	298.7	182.9	537.1	902.9
5	62-70	315.9	243.4	568.0	872.0	261.6	238.7	567.5	872.5
6	76-84	350.0	265.3	563.7	876.3	266.2	229.5	551.7	888.3
7	90-98	352.5	254.6	575.6	864.4	301.7	219.6	548.4	891.6
8	104-112	376.5	236.8	552.2	887.8	374.6	198.7	532.1	907.9

TABLE VI

AVERAGE NUMBER AND LENGTH OF TIMES RUMINATING PER 24 HOURS BY HOLSTEIN AND JERSEY CALVES DURING EACH PERIOD

Period	Age	Holstein		Jersey	
		Av. Times Per Day	Av. Length of Each Time	Av. Times Per Day	Av. Length of Each Time
	(Days)	(No.)	(Min.)	(No.)	(Min.)
1	6-14	4.8	13.3	2.5	12.9
2	20-28	10.1	19.5	8.8	20.1
3	34-42	11.7	23.4	12.6	23.0
4	48-56	11.5	25.1	11.5	25.9
5	62-70	11.7	27.8	10.2	25.6
6	76-84	13.1	26.7	10.2	26.1
7	90-98	13.4	26.4	11.9	25.4
8	104-112	14.0	26.9	15.3	24.5

Blood glucose determinations. The average amount of blood glucose for Holstein and Jersey calves at weekly intervals is shown in Table VII. By the sixth week of age both Holstein and Jersey calves showed a leveling off of the decreasing trend of blood glucose levels. After this age, values of about 60 mg. % were maintained throughout the remainder of the study with the weekly averages ranging from 55.6 to 67.4 mg. %. The range for individual Holstein calves was 117.0 mg. % for one 1-week-old calf to 35.0 mg. % for one 16-week-old calf. There was a range from 115.0 mg. % at 1 week of age to 46.0 mg. % at 16 weeks of age for individual Jersey calves.

The effect of weaning on glucose level in the blood is shown in Table VIII. In constructing this table, the data were arranged according to time before and after weaning. The weekly average blood glucose for Holsteins before weaning ranged from 117.0 mg. % (one calf) to 75 mg. %, and after weaning 56.5 to 64.5 mg. %. Weekly average blood glucose values for Jerseys ranged from 71.2 to 88.3 mg. % before weaning and 49.8 to 66.1 mg. % after weaning. In both breeds there was a progressive decline in blood sugar until the calves weaned, at which time it dropped abruptly by 18.5 mg. % for Holsteins and 10 mg. % for Jerseys. After weaning, the blood sugar remained uniform, averaging 61.1 mg. % (Holstein) and 59.5 mg. % (Jerseys).

TABLE VII

AVERAGE WEEKLY BLOOD GLUCOSE FOR JERSEY AND HOLSTEIN CALVES

Period	Age	Holsteins		Jerseys	
		Determinations	Glucose	Determinations	Glucose
	(Days)	(No.)	(Mg. %)	(No.)	(Mg. %)
1	3-7	3	97.0	4	89.6
2	10-14	3	92.0	6	90.0
3	17-21	3	92.0	7	71.3
4	24-28	5	81.0	7	72.0
5	31-35	4	90.7	5	67.0
6	38-42	4	70.7	6	60.0
7	45-49	4	61.5	5	63.8
8	52-56	4	63.0	6	57.6
9	59-63	4	59.5	6	62.7
10	66-70	5	58.0	7	56.9
11	73-77	5	63.6	8	58.1
12	80-84	5	67.4	8	57.5
13	87-91	8	61.6	9	60.3
14	94-98	9	61.0	7	55.6
15	101-105	10	61.1	9	63.0
16	108-112	9	56.7	9	59.0

TABLE VIII

EFFECT OF EXCLUDING MILK FROM THE DIET OF HOLSTEIN AND JERSEY CALVES ON BLOOD GLUCOSE LEVELS

	Holsteins		Jerseys	
Time Before Weaning	Determinations	Blood Glucose	Determinations	Blood Glucose
(Wks.)	(No.)	(Mg. %)	(No.)	(Mg. %)
6	1	117.0	1	74.0
5	2	96.0	3	88.3
4	2	90.5	4	79.7
3	3	80.3	4	71.2
2	3	81.0	5	68.6
1	3	75.0	5	68.0
Time After Weaning (Wks.)				
1	4	56.5	6	58.0
2	4	65.0	6	66.1
3	4	56.8	6	59.6
4	4	59.8	6	53.8
5	2	64.5	5	49.8
6	3	62.6	4	63.7
7	3	61.3	3	61.0
8	1	62.0	3	64.0

Time ruminating compared with blood glucose. The decrease of blood glucose found with the advancing age of the calf was accompanied by an increase in ruminating time. This relationship is shown graphically in Figure 17. The blood glucose and ruminating time curves each tended to level off at 5 to 6 weeks of age.

The regression of blood glucose on ruminating time was determined as shown in Figure 18. This indicates that in a nonruminating calf the blood glucose level would be above 90 mg. %. As rumination increases, blood sugar declines. The coefficient of correlation (r) between blood glucose and ruminating time was -0.803 which was significant at the 0.01 level of probability.

Digestive tract observations. Seventeen calves were sacrificed for digestive tract observations. Whether or not the calves were ruminating was determined by the appearance of the rumen contents for 13 calves and by activity observations made of 4 calves. A description of the stomach and its contents was recorded according to the different types of milk used in the ration as shown in Table IX. The calves that were fed reconstituted skim milk or a mixture of reconstituted whey and skim milk had rumens that were more nearly like mature rumens than did the calves that were fed the other types of milk. The contents of the abomasums from these calves contained large

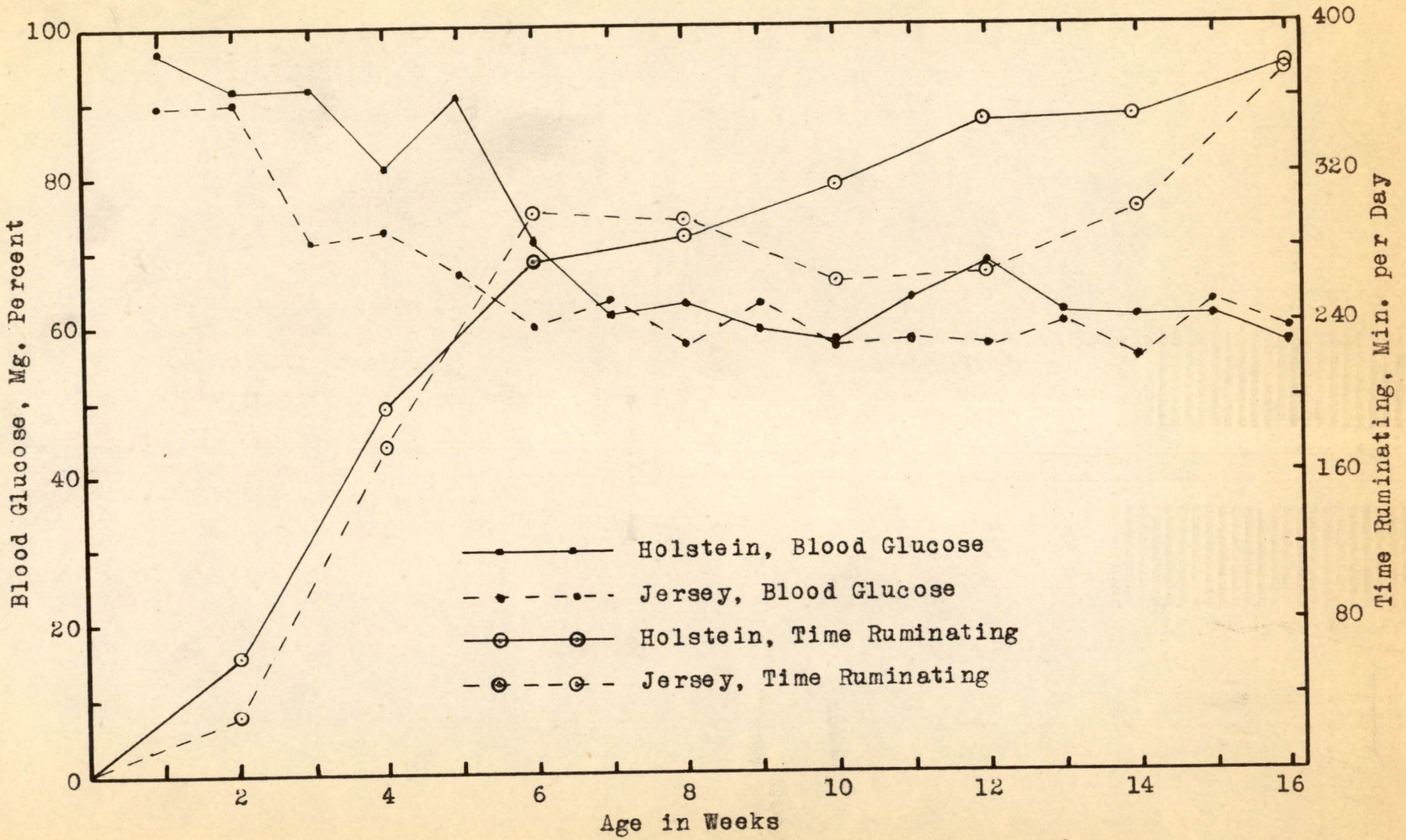

Fig. 17. Blood glucose and rumination time compared for Holstein and Jersey calves.

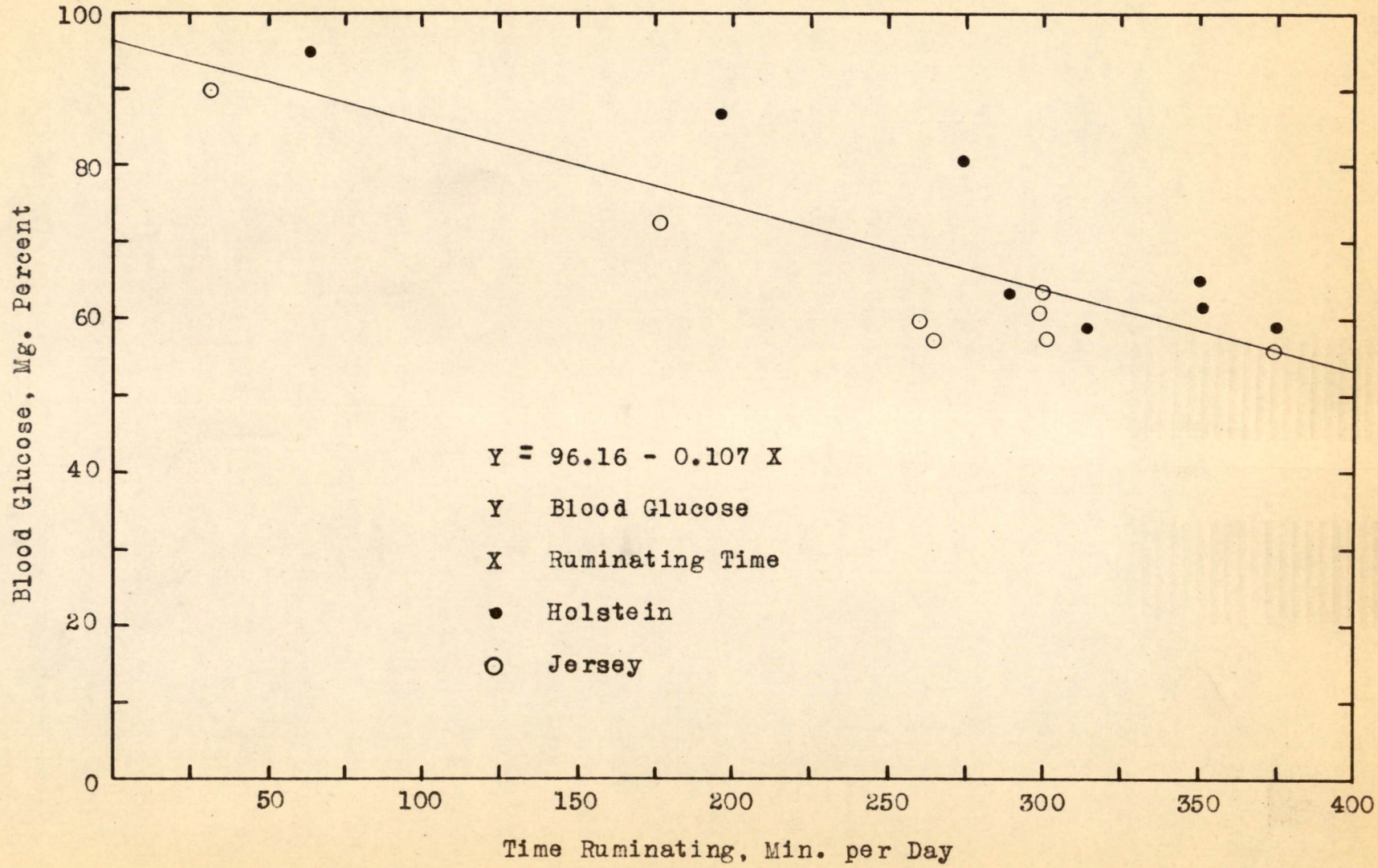

Fig. 18. Correlation of the average blood glucose and time spent ruminating for Holstein and Jersey calves up to 16 weeks of age.

pieces of curd and had an acid-whey odor. All other calves had poorer curd development and an abnormal odor in their abomasums.

Weights of the empty organs and of the contents of the stomachs of the calves, and the pH of the stomach and small intestine contents were determined. These data are presented in Table X according to the development of rumination. The abomasum was more acid than the rumen-reticulum-omasum for ruminating and nonruminating calves. The closer the contents of the small intestine were to the large intestine, the less acid they were. The contents of the digestive tract of the nonruminating calves were slightly more acid than were the digestive tract contents of the ruminating calves.

The empty weights and content weights of the rumen-reticulum-omasum were greater for ruminating calves than for nonruminating calves. The empty and content weights of the abomasum were greater for the nonruminating calves. The empty abomasums and the contents of the abomasums of nonruminating calves were heavier than were the rumen-reticulum-omasums. The contents and empty rumen weighed more than the abomasum in ruminating calves.

Calves 474, B-787, and B-792 were observed for 24 hours before sacrificing. The time spent ruminating, eating and drinking, standing, and lying were recorded. These

TABLE IX

A DESCRIPTION OF THE STOMACH AND ITS CONTENTS TAKEN FROM NORMAL, HEALTHY CALVES WITH VARIED TYPES OF MILK IN THEIR DIETS

Type of Milk in Ration	No. of Calves	Av. Age in Days	Rumen-Reticulum-Omasum	Abomasum
Whole	3	16	Organ appearance normal, gassy, normal contents odor, well chewed hay and grain, some shavings and straw, definate papillary development.	Organ appearance normal, rancid fat odor, small curd (0.5" and less), sone fine hay and grain, straw color liquid.
Dry skim (Reconstituted)	3	16	Organ appearance normal, odor nearly same as normal adult, finely macerated hay, grain, bedding, some hair present, tan to greenish-brown color.	Organ appearance normal, very large, fist sized, firm curd present, whey like cottage cheese whey, mild acid odor, not putrid, some fine hay, meal present.
Dry skim and Dry whey (Reconstituted)	3	14	Organ appearance normal, odor normal for rumen, no free liquid in contents, like mash, much gas trapped in contents, nonruminating calf had liquid rumen contents, solids poorly chewed, straw, hay and grain.	Normal organ appearance, whey odor, material from rumen, brown color, contained much gas, meal from rumen. Nonruminating calf had no curd, bloated abomasum. all liquid, light green color.

TABLE IX (continued)

A DESCRIPTION OF THE STOMACH AND ITS CONTENTS TAKEN FROM NORMAL, HEALTHY CALVES WITH VARIED TYPES OF MILK IN THEIR DIETS

Type of Milk in Ration	No. of Calves	Av. Age in Days	Rumen-Reticulum-Omasum	Abomasum
Dry skim and Soy flour (Reconstituted)	2	13	Normal organ appearance, liquid like dark pea soup, poorly chewed solids, mostly hay.	Normal organ appearance, soy flour odor, few fine curd particles, mush-like consistency, yellow to light brown color.
Dry skim, Dry whey, and Soy flour (Reconstituted)	4	14	Normal organ appearance, normal rumen odor, well macerated hay and grain, liquid strained out like pea soup. Nonruminating calves had putrid odor, liquid contents.	Normal organ appearance, ruminating and nonruminating calves had whey odor, cream to tan colored liquid, small curds, not firm, fine sediment, probably soy flour.
Whole, Dry skim, Dry whey, and Soy flour	1	15	Normal organ appearance, calf not ruminating, not normal rumen odor, but not offensive, contained much coarse, poorly chewed straw, hay, and grain, large amount of brown-gray colored liquid.	Normal organ appearance, not ruminating, liquid was like whey in color and odor with cream colored sediment, curds soft, medium in size, mealy material and grain settled to bottom.

TABLE X

AVERAGE EMPTY ORGAN AND CONTENTS WEIGHTS AND pH OF THE CONTENTS OF THE STOMACH AND THE SMALL INTESTINE FOR RUMINATING AND NONRUMINATING CALVES

Organs	11 Ruminating Calves (14-22 days old)			5 Nonruminating Calves (12-15 days old)		
	Empty Wt.	Wt. of Contents	Acidity of Contents	Empty Wt.	Wt. of Contents	Acidity of Contents
	(g.)	(g.)	(pH)	(g.)	(g.)	(pH)
Rumen-Reticulum-Omasum	325.9	1063.8	5.21	266.4	809.2	5.09
Abomasum	209.8	1389.2	4.91	258.0	2201.8	4.90
Duodenum			5.72			5.17
Jejunum			5.83			5.60
Ileum			6.74			5.73

activities are shown in Figures 19, 20, and 21. The time of day that each calf was engaged in the activities, and the total time for each activity are shown graphically.

Most of the time spent eating was seen at feeding time with other short periods scattered throughout the day. No rumination was observed at feeding time, but the calves ruminated at random during the remainder of the day. The average length of the periods of rumination during the day was 17.7 minutes for calf 474 (22 days old) as shown in Figure 19. The average length of periods of rumination for calf B-787 (14 days old) was 12.5 minutes (Figure 20). The average length of periods of rumination for calf B-792 (18 days old) was 8.2 minutes (Figure 21).

Another calf which was sick was observed for 24 hours at 5-minute intervals before a post-mortem examination was made. At no time was this calf observed ruminating. The contents of the rumen and abomasum of this calf were very similar to the other nonruminating calves that were sacrificed. It had liquid rumen contents with large, poorly chewed pieces of hay and bedding. The abomasum was devoid of any large pieces of curd and had a very foul odor like rancid fat.

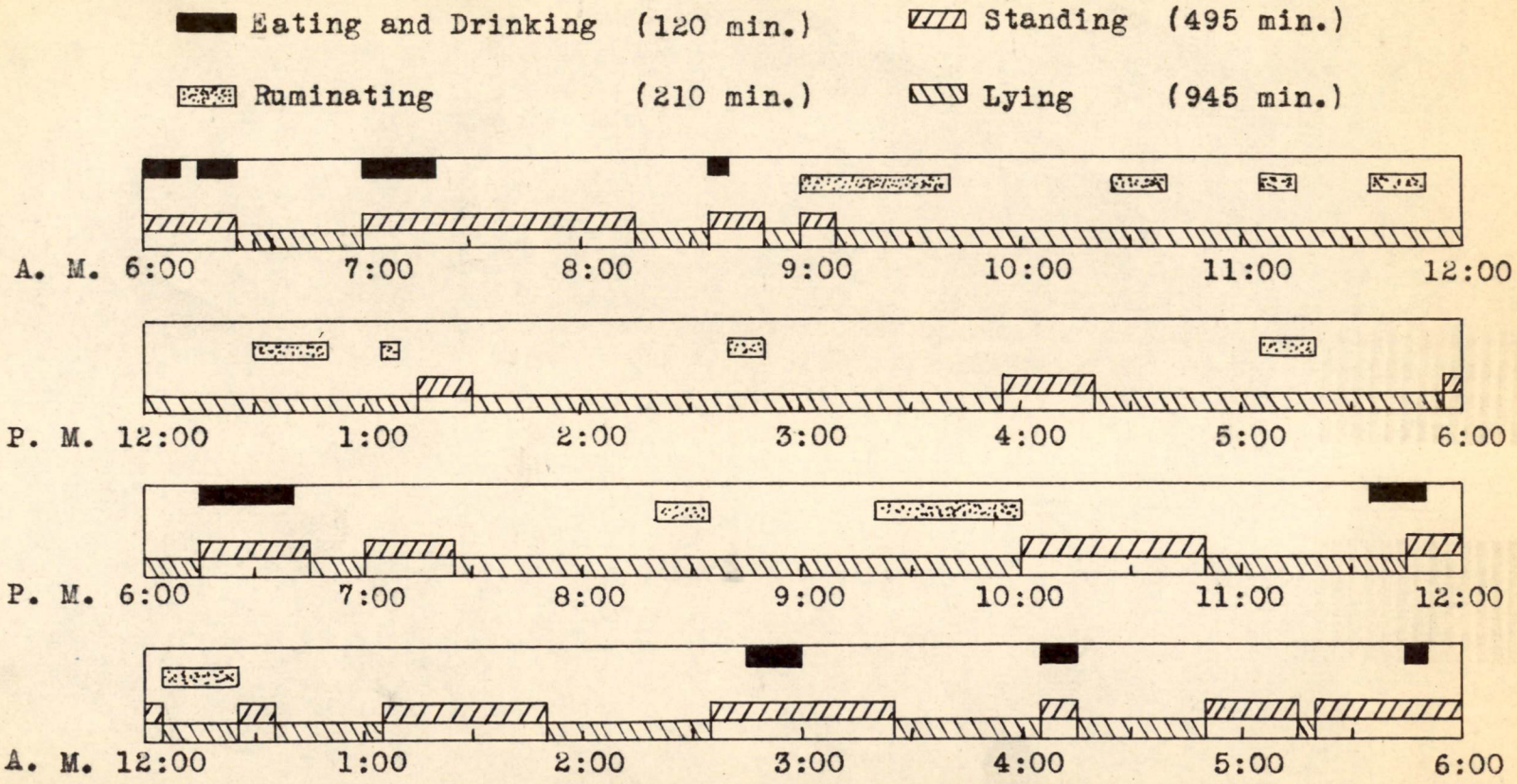

Fig. 19. Calf 474 (22 days old), Time eating and drinking, ruminating, standing, and lying for a 24-hour period (5-minute intervals).

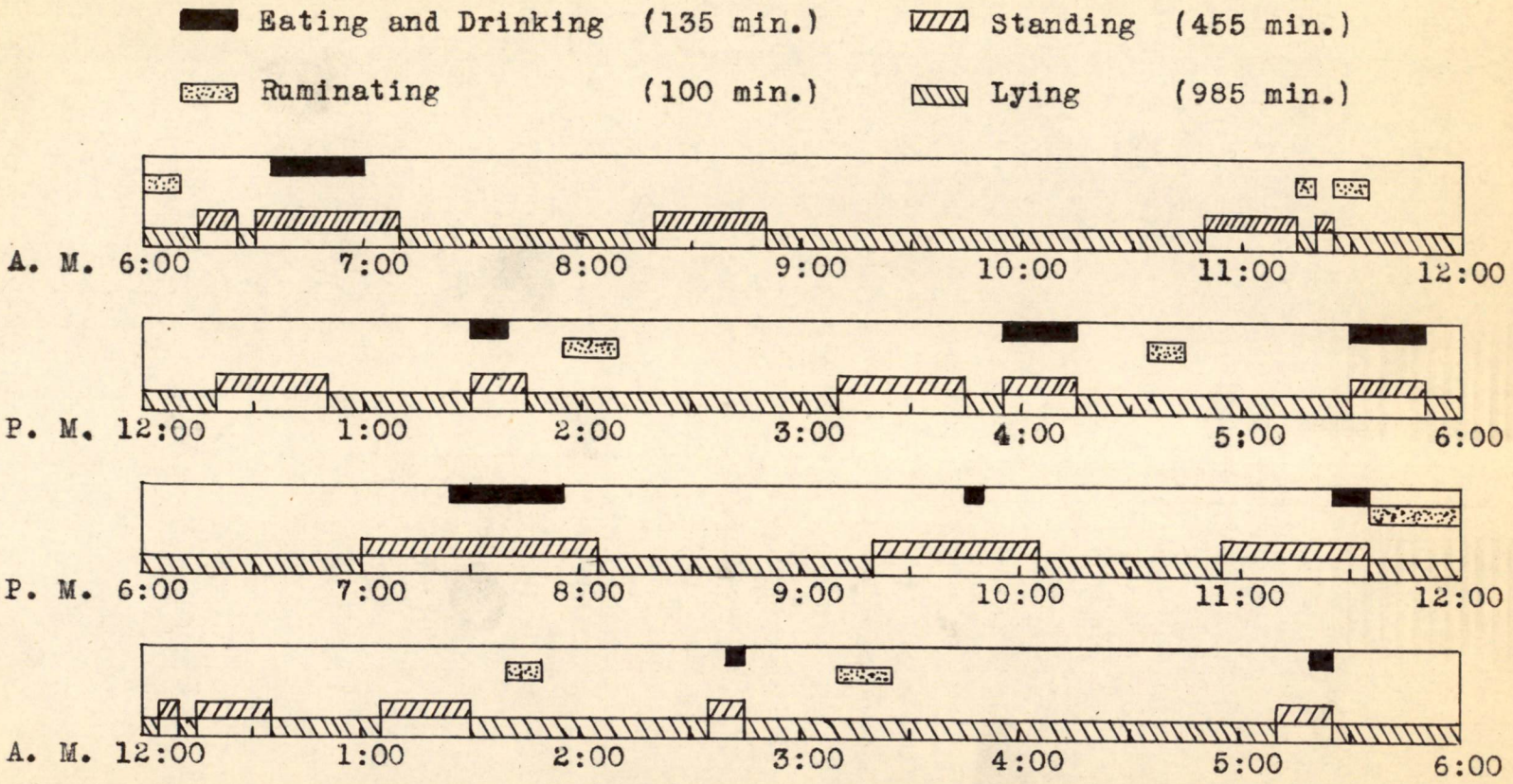

Fig. 20. Calf B-787 (14 days old), time eating and drinking, ruminating, standing, and lying for a 24-hour period (5-minute intervals).

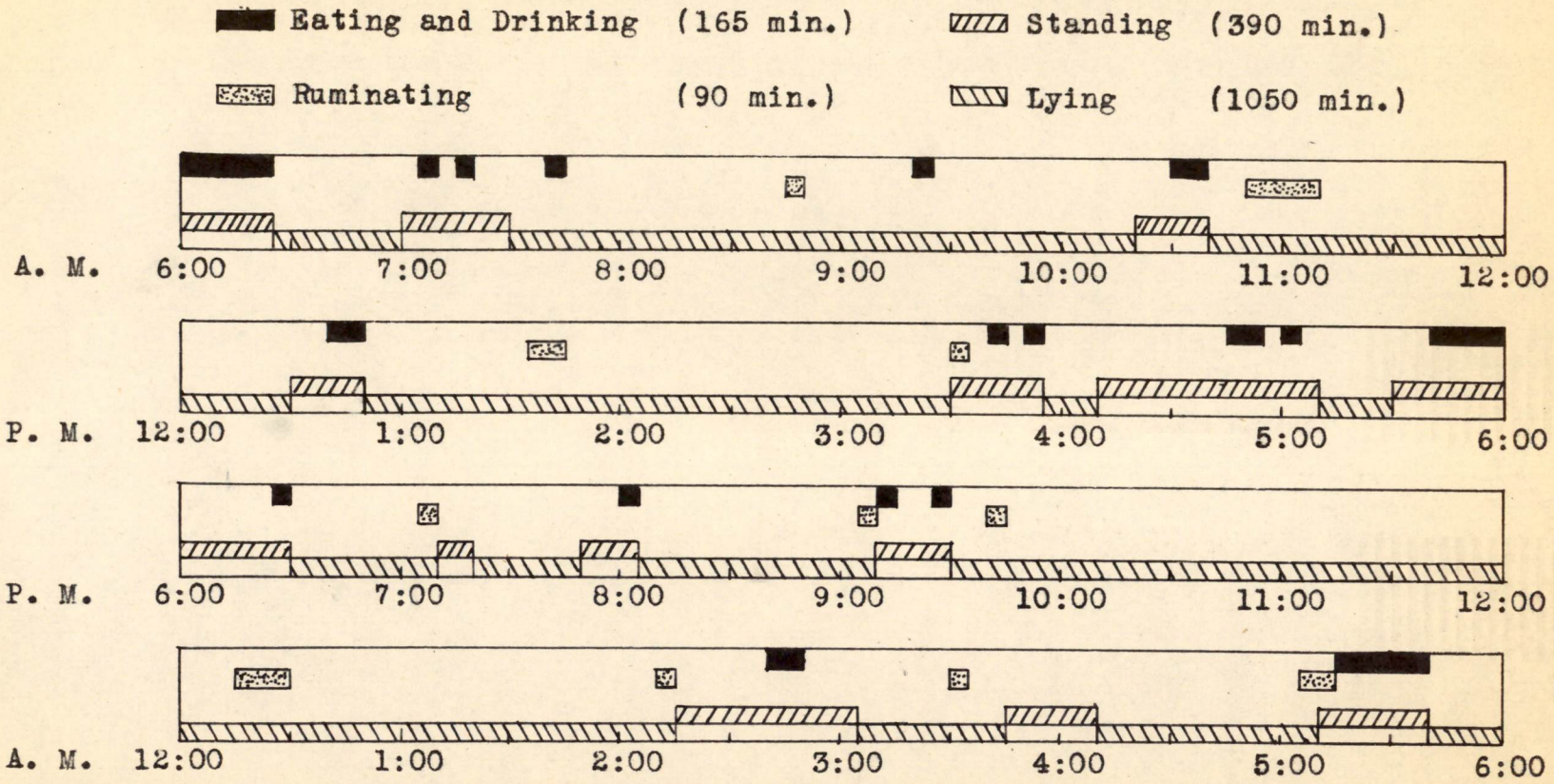

Fig. 21. Calf B-792 (18 days old), time eating and drinking, ruminating, standing, and lying for a 24-hour period (5-minute intervals).

DISCUSSION

These studies have shown that the rumen in healthy calves begins to develop at an early age and approaches mature function rapidly. No other studies have been found that reported the progression of rumination as a result of direct observations.

The average percentage of calves observed ruminating was higher for Holsteins than for Jerseys in all 24-hour periods. The percentage was highest for Jerseys during the night hours of Period 3 and 4 (34-42 and 48-56 days old). There was also a higher percentage of Holstein calves eating and drinking than were Jersey calves, except in Period 1 (6-14 days old), when little difference was found. This was probably because the Holsteins were larger calves with more stomach capacity than the Jerseys.

The highest percentage of calves eating and drinking was observed between 5:00 o'clock and 7:00 o'clock both morning and night. Feeding was done during this period. Very little rumination was done while standing by either Holsteins or Jerseys. The highest percentages of calves ruminating were recorded at the times when a high percentage of calves were lying.

The age at which Jersey and Holstein calves started to ruminate was shown previously in Table IV. Over half

of the calves in both breeds started to ruminate before or during Period 1 (6-14 days old). The remainder of the Holsteins and all but one of the Jerseys started to ruminate after Period 1, and before or during Period 2 (20-28 days old). Thus the onset of rumination for nearly all the calves in both breeds had occurred by 4 weeks of age.

The time spent ruminating and the age of the youngest and oldest calves to start ruminating were stated previously. When the calves started to ruminate at about 1 to 2 weeks of age, the time spent ruminating advanced slowly with age. When the calves started to ruminate as late as 3 to 4 weeks of age, the time spent ruminating progressed rapidly. In either case, mature type rumination (as measured by time observations) was reached at about the same age.

Time spent ruminating by Holstein calves increased during the intervals between Periods 1 through 3 (6-14 through 34-42 days old) nearly five times faster than in the remainder of the study (up to 112 days of age). The increase during the intervals between Periods 1 through 3 for Jersey calves was over six times greater than the increase during the remainder of the study. It appears then, that rather mature rumination had developed by 6 to 8 weeks of age.

Castle, Foot, and Halley (8) observed four Shorthorn cows that ruminated an average of 336 minutes per 24 hours in a pasture management study. Similar results have been reported by others (15, 20, 27). The rapid rate of increase of ruminating time for Jersey and Holstein calves started to level off during Period 3 (34-42 days old). At this age the average ruminating time was close to the time found in the studies mentioned above. The gradual increase in rumination time after this age could be due to increased rumen capacity and consumption of larger proportions of hay.

The number of times per day that the calves ruminated and the average length of each time increased as the Holstein and Jersey calves aged up to 34 to 42 days of age. Apparently, the maximum length of times ruminating was reached at about the same age as the mature level of total time ruminating was reached.

Several investigators (25, 29, 32, 38, 39, 58) have suggested that the amount of glucose in the blood of ruminants is an indication of rumen development. McCarthy and Kesler (38) found the blood glucose level for calves under 7 days of age to be 113.4 mg. %. The glucose decreased to 43.9 mg. % at 42 days of age, and a range of 40 to 60 mg. % was maintained throughout the remainder of the 112 day study. The other investigators mentioned above have

reported similar trends. The amount of blood glucose found in the calves in this study, as well as the decline of glucose as the calves aged, is in agreement with these previous studies.

A marked drop in blood glucose was found after the removal of milk from the diet of Jersey and Holstein calves. This was shown previously in Table VIII. Apparently, the amount of blood sugar is partly related to the sugar in the diet as is suggested by Hodgson (25). This is not the complete reason for the blood glucose change, because it begins to decrease well before weaning, and this decrease is accompanied by an increase in amount of milk fed.

As rumination time increased, the blood glucose decreased for Holstein and Jersey calves. The blood glucose curve leveled off at about 6 weeks of age as did the rumination time curve, which indicates that rumen development is well advanced by this age.

According to the descriptions of the digestive tracts, the calves fed reconstituted dry skim milk or dry skim milk and dried whey had rumens that were developed more than calves fed the other milk rations. The dry skim or dry skim and dry whey may not have satisfied the calves' appetite as much as did the other milk rations. This unsatisfied appetite would have encouraged more roughage consumption.

The weights of the empty organs and organ contents of the slaughtered calves were shown previously in Table X. The rumens of the nonruminating calves weighed less, and the abomasum weighed more empty and full than these organs in the ruminating calves. This helps to confirm the belief that the rumen is less important in the digestion in the young nonruminating calf than is the abomasum. As the rumen and rumination develop, the abomasum becomes less and less important in digestion.

Whether or not the slaughtered calves were ruminating was determined by the appearance of the contents of the rumen. Finely chewed, well mixed food material, and absence of free liquid indicated that rumination had begun. Unchewed food, large pieces of hay and bedding, and excess liquid were considered to indicate the absence of rumination. One calf was observed at 5-minute intervals for 24 hours before the post-mortem examination, and no rumination was recorded. This calf's stomach contents were like the stomach contents of the previously killed nonruminating calves. Three other calves were observed before slaughtering, and were found to be ruminating. Their stomach contents were like the previously observed contents from the stomachs of the ruminating calves. This suggests that criteria used for the determination of development of rumination were correct.

SUMMARY

A total of 76 Holstein-Friesian, Jersey, and grade calves were used in this study. These calves were fed a normal hay and grain ration and reconstituted skim milk (fortified with aureomycin and vitamin A and D) at 10% body weight. They were kept in individual pens with solid sides.

Observations of daily activities of Holstein and Jersey calves were made at 5-minute intervals every 2 weeks up to 112 days of age. Activities that were observed included rumination, eating and drinking, standing, and lying. The percentage of Holstein calves ruminating was greater than Jerseys in each of the 8 observation periods. In nearly all the periods, a higher percentage of calves in both breeds ruminated at night than during the day. The percentage of Holstein calves eating and drinking was 3.6% higher during the day than during the night, and it was 5.4% higher during the day for Jersey calves. There was a higher percentage of Holstein and Jersey calves standing during the daylight hours throughout the study.

Percentages of Holstein and Jersey calves engaged in all activities have been shown graphically. Rumination time was lowest for both breeds at feeding time in all

periods and was fairly uniform during the remainder of each period. All Holstein calves had started to ruminate by Period 2 (20-28 days old), and all Jerseys had started by Period 3 (20-28 days old).

By Period 3 (34-42 days old), both Holstein and Jersey calves spent an amount of time ruminating that compared favorably to time spent ruminating by mature cows. At this point Holsteins ruminated an average of 273.9 minutes per 24 hours, and Jerseys ruminated an average of 300.0 minutes per 24 hours. At this same time the increase in length of times ruminating ceased and remained constant during the remainder of the study.

Blood glucose determinations were made for Holstein and Jersey calves, and these data were used as an indication of rumen development. Blood glucose decreased as the calves aged up to 5 to 6 weeks. Both rumination time and blood glucose leveled off at this point and both were at mature levels.

Post-mortem examinations were made of the digestive tracts of 11 ruminating and 5 nonruminating grade calves. These calves were assigned at random to 6 groups, differing only in type of milk in the ration. Ruminating calves fed dry skim milk or dry skim milk and dried whey had rumens that were more developed than did calves fed the other types of milk. These same types of milk produced larger

curd formations and a more "whey"-like odor in ruminating and nonruminating calves than did the other types of milk.

Three calves were observed before slaughtering, and their activities are shown graphically for 24 hours at 5-minute intervals. These calves, as well as the other slaughtered ruminating calves, had mature types rumens as judged by appearance of organs and contents. One calf observed in this same manner had not ruminated. The stomach contents of this calf showed the same definite signs of undevelopment that were observed in the other slaughtered nonruminating calves.

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