THE RESPONSE OF GROWING DAIRY HEIFERS TO FREQUENCY OF FEEDING

by

Allen Huff Rakes

Thesis submitted to the Graduate Faculty of the Virginia Polytechnic Institute in candidacy for the degree of

MASTER OF SCIENCE

in

DAIRY SCIENCE

APPROVED:

Director of Graduate Studies

Dean of Agriculture

APPROVED:

Head of Department

Supervisor or Major Professor

June, 1957

Blacksburg, Virginia

TABLE OF CONTENTS

TABLES

Page

FIGURES

INTRODUCTION

At least five million heifers are raised annually in the United States to maintain the dairy cattle population and provide for our future needs. These animals are in reality the very foundation of the dairy business and the prosperity of everyone connected with it are dependent, at least to a certain extent, upon how well and how economically these animals are produced. Any practice that might possibly increase the efficiency with which these animals are raised is certainly worthy of thorough study and consideration.

In the past the livestockman has paid little attention to the effect that frequency of feeding may have on the efficiency with which his animals convert feed to milk, meat, and eggs. This is surprising when one considers the feeding behavior of the animal in its native or unconfined state.

In its wild state the animal took in food throughout the day and also undoubtly at night. The quantity eaten and the frequency of intake was entirely dependent upon the desire of the animal and the availability of feed. This condition still exists to a very large extent in the case of the free-grazing animal. However, with the closely confined or hand-fed animal both the quantity of feed eaten and the frequency of intake are regulated according to the judgment of the husbandman. Since this is a definite change from the feeding habits of the animal in its native state, it is conceivable that some

change in the efficiency of feed utilization, if not the overall physiology, of the animal has occurred as a result of domestication.

Like the livestockman the research worker has considered frequency of feeding to have little or no influence on his research results.

A limited amount of work (15,70,27) has demonstrated that frequency of feeding is important in livestock production. If additional work confirms these results, it will become necessary to interpret past feeding experiments in the light of these new findings and to give more attention to frequency of feeding in future nutritional research. Such information would be of considerable practical importance since it would be a comparatively simple matter to design automatic feeders which would feed animals at periodic intervals.

The present study was initiated to obtain data on the differences in body weight gain, digestion coefficients, heart rate, rectal temperature, rumination time, and rate of passage of food of dairy heifers fed equalized intakes of feed two and ten times daily.

REVIEW OF LITERATURE

The literature concerned with increased frequency of feeding of animals is somewhat limited. Only three studies in which controlled frequency of feeding in excess of two times daily was practiced has been reported.

The first of these studies was conducted by Gordon and Tribe (15). Twenty-two Cheviot ewes were paired and divided into two equal groups which were comparable in age, body weight, and previous history. The sheep were penned singly, and each one was fed a daily ration consisting of one pound of chopped hay mixed with one and one-half pounds of a concentrate mixture consisting principally of ground corn and small grains. The animals were offered ad libitum supply of water and had access at all times to both plain salt and mineral licks. During the first part of the experiment, which lasted for a period of nine weeks, group A was fed eight times daily at approximately hourly intervals between the hours of 9:30 a.m. and 5:15 p.m. Group B received its daily ration as one large feed at 9:15 a.m. For the second nine-week period the treatments were reversed, group B being given the frequent feeding treatment and group A fed once daily. In both trials the members of each individual pair received exactly the same total amount of feed daily, the only difference being the number of times daily which they were fed. During period one, group B, on one feed daily,

increased in total body weight by only 18 pounds. On the other hand, group A fed eight times per day, gained 96 pounds. During period two, group A, now fed only once each day, made a total live-weight increase of 33 pounds, whereas group B, now fed eight times daily, gained 151 pounds. For the entire eighteen week feeding period the animals receiving their daily feed allowance once daily gained a total of 51 pounds, while the frequently-fed animals gained a total of 247 pounds.

In a preliminary study Thomas and Mochrie (27) found that heifers fed four times daily gained significantly faster than heifers fed the same quantity of feed either once or twice daily. There was no significant difference in the daily gains of the animals fed once and twice daily. The ration consisted of hay and grain.

Later work by Mochrie, et al. (20) confirmed these results. In this study Holstein steers were fed hay and grain either once or four times daily. The animals fed once daily received their entire ration at 7:00 a.m. and 7:00 p.m. The average daily gains were 1.03 and 1.21 pounds for the single-fed and frequently-fed group, respectively. This difference in gain of 0.18 pounds was highly significant.

Mochrie, et al. (20) also studied the effect of frequency of feeding on milk production. Twelve Holstein first-calf heifers were used in a three-period (six weeks each) switchback trial to test the utilization of a concentrate-alfalfa hay ration when fed twice daily, four times daily, and eight times daily. Milk production, fat test, or live weight changes were not significantly influenced by feeding frequencies.

It was concluded that at the frequencies studied, frequent feeding of equalized daily intakes appears to increase feed utilization for growth but not for total energy output by lactating heifers.

Although very few workers have investigated the possibilities of feeding animals more than twice daily, there are scattered accounts of studies in which the effectiveness of once and twice-a-day feeding have been compared.

Dawson and Kopland (12) employed ten Holstein cows in a double-reversal design to study the effect of once and twice-a-day feeding on milk production. The experimental periods were 50 days in length. One group received all of their day's feed in the morning; the other group received half of the day's feed in the morning and half in the afternoon. The cows fed twice-a-day ate ten per cent more alfalfa and produced six per cent more milk than the animals given their daily allowance in one feeding. The differences in concentrate consumption were not significant.

Trials were conducted at the Tennessee Station (1) in which two uniform lots of good native yearlings were fed a fattening ration for three one hundred and twenty day periods. Lot one was fed twice daily and lot two once daily. The average daily gain for the animals fed once daily was 1.80 pounds as compared to 1.85 pounds for the animals fed twice daily.

Feeding trials at Wisconsin (2) indicated that steers fed twice daily gained more than those fed once daily. In three periods of 159 days each, steers fed twice daily averaged 2.67 pounds gain per day as compared to 2.57 pounds for those fed once daily.

In addition to the work on controlled frequency of feeding already enumerated, several workers (4,8,18) have studied the effects of self or free-choice feeding on swine and sheep and have reported favorable results. Since, in these studies, no data concerning the number of times daily the self-fed animals consumed food, no valid conclusions can be drawn relative to the effects of frequency of feeding. However, the results indicate the need for further investigation.

The foregoing review indicates that, although very few workers have seriously considered them, there are definite possibilities of certain differences existing between animals fed once or twice daily and those fed more frequently. Whether these differences, if they exist, are significant and economically important or whether they are minute, is a question that cannot be fully answered on the basis of existing data. The need for the establishment of the existance of these differences and the determination of their scope is readily apparent.

METHOD OF PROCEDURE

Twelve dairy heifers (eight Holsteins, four Guernseys) ranging in weight from approximately 300 to 500 pounds were used as the experimental animals. The animals were divided into six pairs of two animals each with the animals in each pair being as near alike as possible with respect to body weight. One member of each pair was then allotted at random to the twice-a-day feeding treatment and the other member to the ten times-a-day feeding treatment.

The animals were brought up to a maximum feed intake (amount consumed without appreciable refusal) during a twenty-one day preliminary period. The level was adjusted so that the members of each pair received the same total daily feed intake, and this level was held constant throughout the two fifty day experimental periods which followed.

During the first experimental period, one-half of the animals received their daily feed allowance in two equal feedings daily at 8:00 a.m. and 5:00 p.m., and the remainder of the animals received the same quantity of feed divided into small equal portions and fed at hourly intervals between 8:00 a.m. and 5:00 p.m. At the end of this period the treatments were reversed abruptly, no change-over time allotted between period, and feeding was continued for another fifty days.

The feed consisted of mixed, medium quality hay which was chopped (approximately two to four inches in length) to facilitate feeding and to discourage feed refusal. The hay was core-sampled periodically before chopping for proximate analysis. Daily feed consumption was recorded and all refused feed was weighed back. Water and salt was provided ad libitum and steamed bone meal was offered to the animals periodically.

All animals were weighed on three consecutive days at the beginning and end of each experimental period. In addition, weights were taken on three consecutive days at ten-day intervals between the beginning and end of each period. Weighings were made in the morning prior to feeding and mean valves were used in analysis of the data.

Conventional digestion trials employing all animals were conducted during the latter part of each experimental period. Feces were totally collected over seven-day periods. Proximate analysis on all feed and fecal samples were carried out according to the methods outlined by the Association of Official Agricultural Chemists (3).

All appropriate data was subjected to statistical analysis according to the methods used by Cochran and Cox (10).

During the period from 11:00 a.m. until 12:00 noon each day (excluding a break-in period at the beginning of trial one) the following physiological activity measurements were recorded for each animal:

1. Heart Rate - The heart rates of the heifers were measured with the aid of a stethoscope. The diaphram was placed over the lower thoracic region just behind the shoulders. When the sound of the heart action was recognized, consecutive fifteen second readings were taken until three identical valves were obtained. When this degree of stability was established, the observed fifteen second value was multiplied by four and the result recorded. The average values for each experimental period were used in analysis of the data. All of the measurements were taken by the same person in order to obtain as much uniformity as possible.
2. Rectal Temperature - The body temperatures of the heifers were measured with the aid of a clinical thermometer. The thermometer was placed in the rectum of the animal (approximately three inches) and allowed to remain for three minutes. It was then removed, and the reading was recorded in degrees Fahrenheit. The instrument was vibrated until the reading was below 98° Fahrenheit before each measurement was attempted. The average values for each experimental period were used in analysis of the data. An ordinary laboratory thermometer was placed in the barn and the environmental temperature in degrees Fahrenheit was recorded each day just prior to starting the body temperature measurements. These measurements were recorded for general observational purposes, and they were not included in the analysis of the data.

During each digestion trial a three-day rumination-time study was conducted on all animals in the experiment. The rumination time (measured in minutes) was recorded for three twenty-four hour periods during each of the digestion trials. The average values (expressed in minutes per twenty-four hour period) for each study was used in the analysis of data.

During the second digestion trial rate of passage measurements were taken employing stained hay particles and chromic oxide. Three animals from each group were used.

The technique used was essentially that suggested by Balch[5]. A quantity of chopped hay was soaked for six hours in a hot solution containing .5 grams of crystal violet per liter of water. The hay was then removed from the stain solution, washed thoroughly with cold water, and air dried.

A quantity of stained hay equal to approximately four percent of the animal's daily feed intake was given with the first feed allotment on the first day of the collection period. Each animal was also given 15 grams of chromic oxide in a gelatin capsule at this time. Fecal sampling was begun 12 hours after the initial feeding and then at four-hour intervals for the first two twenty-four hour periods. During the third day, samples were taken at six-hour intervals. At each sampling time the accumulated feces were weighed, mixed, and a portion taken for stained partical count, chromic oxide, and moisture analysis.

The stained particle count was conducted using the method outlined by Balch[5] with the following modifications: (1) The gauze containing the washed feces was dried for one-half hour in a forced draft oven (85°C.) before counting. This permitted the stained particles to be more easily distinguished than when observed immediately after washing. (2) Stained particle counts were made on three instead of four subsamples from each sample. This was necessitated by the lack of sufficient quantity of feces in some of the samples.

Chromic oxide analysis were made in duplicate on all the samples using the method outlined by Shurch et al.[26].

The mean retention time for each marker was calculated for each animal by the method suggested by Castle[9]. These values were used in the statistical analysis of the data.

RESULTS

Body Weight Gain

The body weight gain data are summarized in Table 1.

TABLE 1

Body Weight Gain Per Treatment Group

Experimental Period	Times Fed Daily	
	2X	10X
	(lbs.)	(lbs.)
Period 1	216	325
Period 2	78	240
Total	294	565

TABLE 2

Analysis of Variance of The Differences in Body Weight Gains

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Variation	11	8,294	754	3.52
Trials	1	2,072	2,072	9.68*
Treatments	1	3,060	3,060	14.30**
Error	10	2,144	214	
Total	23	15,570		

* Significant at the 5% level
** Significant at the 1% level

The total gains made on the twice-a-day and ten times-a-day feeding regimes were 294 and 565 pounds respectively. The difference of 271 pounds was highly significant as indicated in Table 2. The difference in weight gains made during period one and period two was also significant. This might be expected since the level of feed intake was held constant throughout the experiment.

The total body weight of each group throughout the entire experimental period is shown in Figure 1. It is readily apparent that the accumulative effect of frequent feeding tended to become greater with increasing time. The failure to gain weight, or the decrease in weight, which is evident in each group between the 30th and the 40th day of period one and the 90th and 100th day of period two, occurred at the same times the digestion trials were being conducted. Apparently the removal of all bedding and the presence of attendants provided enough stress to prevent any gain in weight during these times.

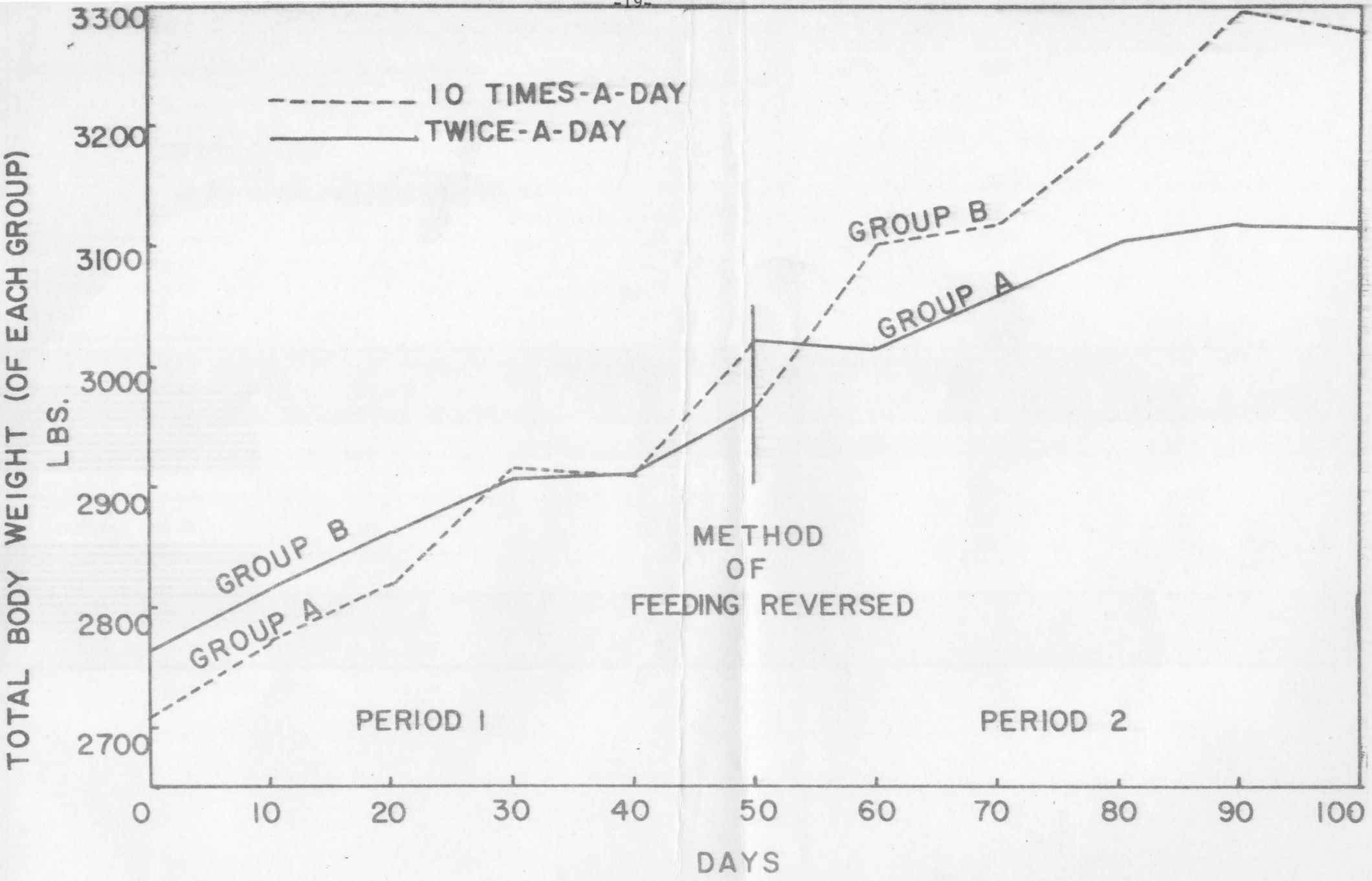

FIGURE. I. CHANGES IN TOTAL BODY WEIGHT OF EXPERIMENTAL GROUPS

It should be noted that when the treatments were switched, a very definite effect was obtained in favor of frequent feeding.

Proximate Analysis of Feed

The proximate analyses on six samples of hay taken periodically throughout the experiment are shown in Table 3.

TABLE 3

The Proximate Analysis of Hay Used in The Experiment (Six Samples)

Sample Number	Dry Matter %	Ether Extract %	Protein %	Crude Fiber %	Nitrogen Free Extract %	Ash %
1	89.23	2.02	11.88	32.98	44.85	8.27
2	87.64	2.20	13.56	27.51	43.53	13.20
3	88.13	2.05	14.13	28.68	44.51	10.63
4	87.24	2.30	12.06	31.37	42.78	11.49
5	88.14	2.10	13.13	29.56	44.61	10.60
6	87.64	2.01	13.13	30.16	44.89	9.81
Average	88.00	2.11	12.98	30.04	44.20	10.67

Feed Consumption and Efficiency of Feed Utilization

The average total feed consumption, average daily feed consumption, and pounds of feed per pound of gain are summarized in Table 4.

TABLE 4

Average Total Feed Consumption, Daily Feed Consumption and Feed Per Pound of Gain

Treatment	(Average) Total Feed Consumption	(Average) Daily Feed Consumption	Pounds Feed Per Pound Gain
	(lbs.)	(lbs.)	(lbs.)
2 X Feeding	6798	11.3	23.1
10 X Feeding	6758	11.3	12.0

Feed consumption was essentially the same for the animals fed twice daily and ten times daily. Thus, in light of the weight gains data one would logically expect the wide difference in efficiency of feed utilization noted in Table 4.

Digestibility Data

A summary of the average coefficients of apparent digestibility is presented in Table 5. These data show that in every instance digestibility was higher in animals fed twice daily than in those fed ten times daily. The statistical analyses presented in Tables 6, 7, 8, and 9 show that the differences in digestibility of dry matter, crude protein, crude fiber, and nitrogen free extract, due to treatments were highly significant. Fat digestion of animals fed twice and ten times daily did not differ significantly (Table 10). It was also found that in the case of protein, nitrogen free extract, and fat

digestibility, differences due to trials were highly significant. The difference between trials was much greater in the case of ether extract than for any of the other constituents. No explanation is readily available to explain these difference between trials.

TABLE 5

Coefficients of Apparent Digestibility of Various Nutrients by Treatment Groups

	Dry Matter %	Protein %	Ether Extract %	Crude Fiber %	Nitrogen-Free Extract %
Trial 1					
2 X Feeding	59.78	63.84	34.79	62.66	57.61
10 X Feeding	57.40	62.19	32.21	59.94	54.25
Trial 2					
2 X Feeding	59.64	66.03	5.17	61.94	59.81
10 X Feeding	56.40	63.82	2.66	57.91	55.86
Average of (2 Trials)					
2 X Feeding	59.71	64.94	19.98	62.30	58.71
10 X Feeding	56.90	63.00	17.44	58.92	55.06

TABLE 6

Analysis of Variance of the Differences in Dry Matter Digestion Coefficients

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Varation	9	15.1252	1.6808	9.1298*
Trials	1	.0769	.0769	.4177
Treatments	1	37.3737	37.3737	203.0076**
Error	8	1.4724	.1841	
Total	19	54.0502		

* Significant at the 5% level
** Significant at the 1% level

TABLE 7

Analysis of Variance of the

Differences in Protein Digestion

Coefficients

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Varation	9	23.5835	2.6203	26.0209**
Trials	1	23.1770	23.1770	230.1589**
Treatments	1	17.9930	17.9930	178.6792**
Error	8	.8056	.1007	
Total	19	65.5591		

** Significant at the 1% level

TABLE 9

Analysis of Variance of the

Differences in Nitrogen Free Extract

Digestion Coefficients

Source of Varation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Varation	9	22.1112	2.4568	1.0641
Trials	1	31.9034	31.9034	15.7091**
Treatments	1	64.1536	64.1536	27.7866**
Error	8	18.4704	2.3088	
Total	19	136.6386		

** Significant at the 1% level

TABLE 10

Analysis of Variance of the

Differences in Ether Extract

Digestion Coefficients

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Variation	9	115.3474	12.8164	1.0264
Trials	1	4,042.4618	4,042.4618	323.7388**
Treatments	1	21.9242	21.9242	1.7558
Error	8	99.8942	12.4868	
Total	19	4,279.6276		

** Significant at the 1% level

Heart Rate

As shown in Table 11, the frequent fed animals exhibited a higher heart rate in both periods than the animals fed twice daily with an average of 72.7 and 62.1 beats per minute respectively.

TABLE 11

Average Heart Rate of Animals

Experimental Periods	Times Fed Per Day	
	2X	10X
	(Beats per Minute)	
Period 1	61.9	68.2
Period 2	62.2	77.1
Average	62.1	72.7

TABLE 12

Analysis of Variance of The Differences in Heart Rate

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Variation	11	158.78	14.43	4.00
Trials	1	128.81	128.81	35.79**
Treatments	1	672.04	672.04	18.67**
Error	10	35.99	3.599	
Total	23	995.62		

** Significant at the 1% level

It should be noted that the frequent-fed animals in this experiment were fed less than one-half hour before the heart rate measurements were taken. It is conceivable that the higher values obtained for the frequent-fed animals were due to the differences in the time since the groups were last fed and not to an overall increase in physiological rate. Blaxter (6) found that feed intake caused a significant increase in the heart rate of dairy cows. No explanation can be offered for the differences between the heart rates obtained during Period 1 and Period 2.

TABLE 13

Average Rectal Temperature of Animals

Experimental Period	Times Fed Per Day	
	2X	10X
	(Fo)	(Fo)
Period 1	101.4	101.9
Period 2	101.0	101.8
Average	101.2	101.9

TABLE 14

Analysis of Variance of The

Differences in Body Temperature

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Variation	9	.33	.036	36 **
Trials	1	.20	.20	20 **
Treatments	1	2.66	2.66	266 **
Error	8	.08	.01	
Total	19	3.27		

** Significant at the 1% level

Body Temperature

The average rectal temperature data are shown in Table 13. The overall average rectal temperature of the frequent-fed animals was 101.9°F., whereas the average for the animals fed twice daily was only 101.2°F. The analysis of variance in Table 14 shows that this difference of .7°F. was not significant at the one percent level of probability.

This difference, like the difference in heart rate between treatment groups, does not necessarily indicate a difference in the rate of overall physiological activity. Forbes and others (14) found that the

heat production in steers decreased with increasing time since the last feeding. It is possible that the difference in rectal temperature obtained are attributable to the differences in the length of the period between the last feeding and the time the measurements were taken.

Since the environmental temperatures during the two periods were not significantly different, no explanation can be offered for the significantly higher values obtained during Trial 1.

Rumination Time

A summary of the average rumination time per twenty-four hour period is given in Table 15. During both experimental periods significantly higher values (Table 16) were obtained for the frequent-fed group. Gordon and Tribe [15], however, found that sheep fed only once a day ruminated longer than those fed eight times a day.

TABLE 15

Average Rumination Time (Per 24-hour Period) of Animals During Trial 1 and Trial 2

Experimental Period	Times Fed Daily	
	2X	10X
	(minutes)	(minutes)
Trial 1	379	470
Trial 2	360	363
Averages	370	417

TABLE 16

Analysis of Variance of The

Differences in Rumination Time

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Variation	9	38,037	4,226	2.33
Trials	1	20,161	20,161	11.11 *
Treatments	1	10,718	10,718	5.91 *
Error	8	14,519	1,815	
Total	19	83,435		

* Significant at the 5% level

It should be noted from Table 17 that the animals fed twice daily spent more time ruminating during the period between 7:00 a.m. and 6:00 p.m. than did those in the frequent-fed group. In the frequent-fed group only 37.17 percent of the total rumination time was recorded during the daylight hours, whereas 58.91 percent of the total rumination time for the twice-daily fed group was recorded during this period. It is evident here, as was noted during the experiment, that the animals fed ten times daily had less opportunity for ruminating during the actual feed period but ruminated more consistantly throughout the remainder of the twenty-four hour period.

TABLE 17

Average Rumination Time (Per 24-hour Period)
of Animals Between 7:00 a.m. and 6:00 p.m. During
Trial 1 and Trial 2

Experimental Period	Times Fed Daily 2X	10X
	(minutes)	(minutes)
Trial 1	238	137
Trial 2	197	172
Averages	218	155

TABLE 18

Analysis of Variance of
The Differences in Rumination
Time Between 7:00 a.m. and 6:00 p.m.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Individual Heifer Variation	9	30,149	335	16.30
Trials	1	51.0	51.0	2.48
Treatments	1	19,971	19,971	9.72 *
Error	8	16,431	2,054	
Total	19	67,063		

* Significant at the 5% level

Rate of Passage

Figure 2 shows the accumulated percent of the total number of stained particles excreted at various intervals after the stained hay was fed. The average mean retention value for the animals in the frequent-fed group was 56.0 hours, whereas it was 62.7 hours for the animals fed twice daily. The slightly faster rate of passage noted in the twice-daily fed group was found not to be significant.

Figure 3 shows the accumulated percent of the total number of milligrams of chromic oxide excreted at various intervals after the animals were given the marker capsules. The average mean retention values were 52.22 hours and 49.82 hours for the twice-daily and the frequent-fed groups respectively. This difference was found not to be significant.

The average mean retention value for all determinations made by the chromic oxide technique was 51.02 hours and 59.35 hours for the stained particle technique. This difference was also found not to be significant.

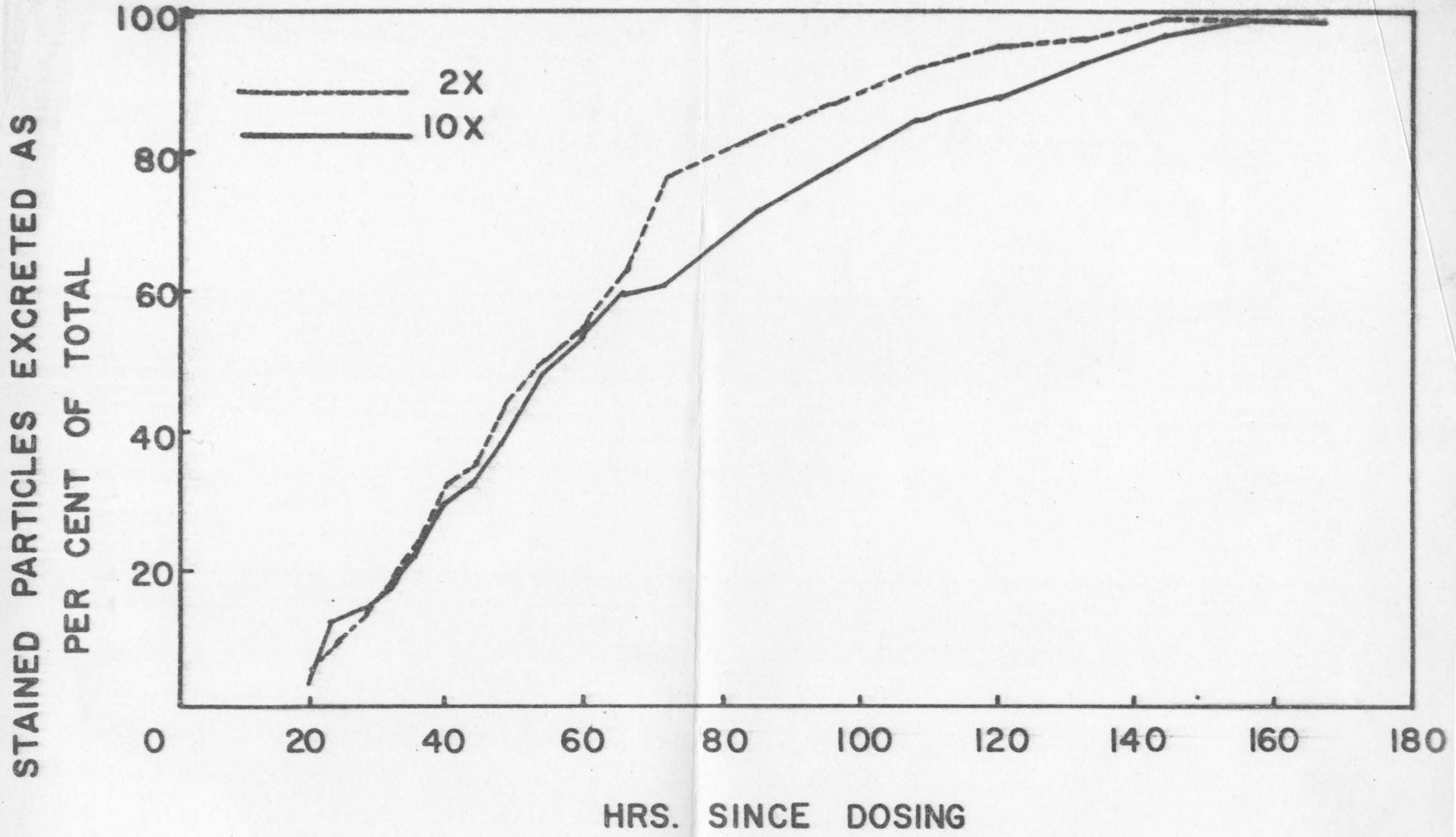

FIGURE 2. CUMULATIVE TOTAL OF THE STAINED HAY PARTICLES EXCRETED

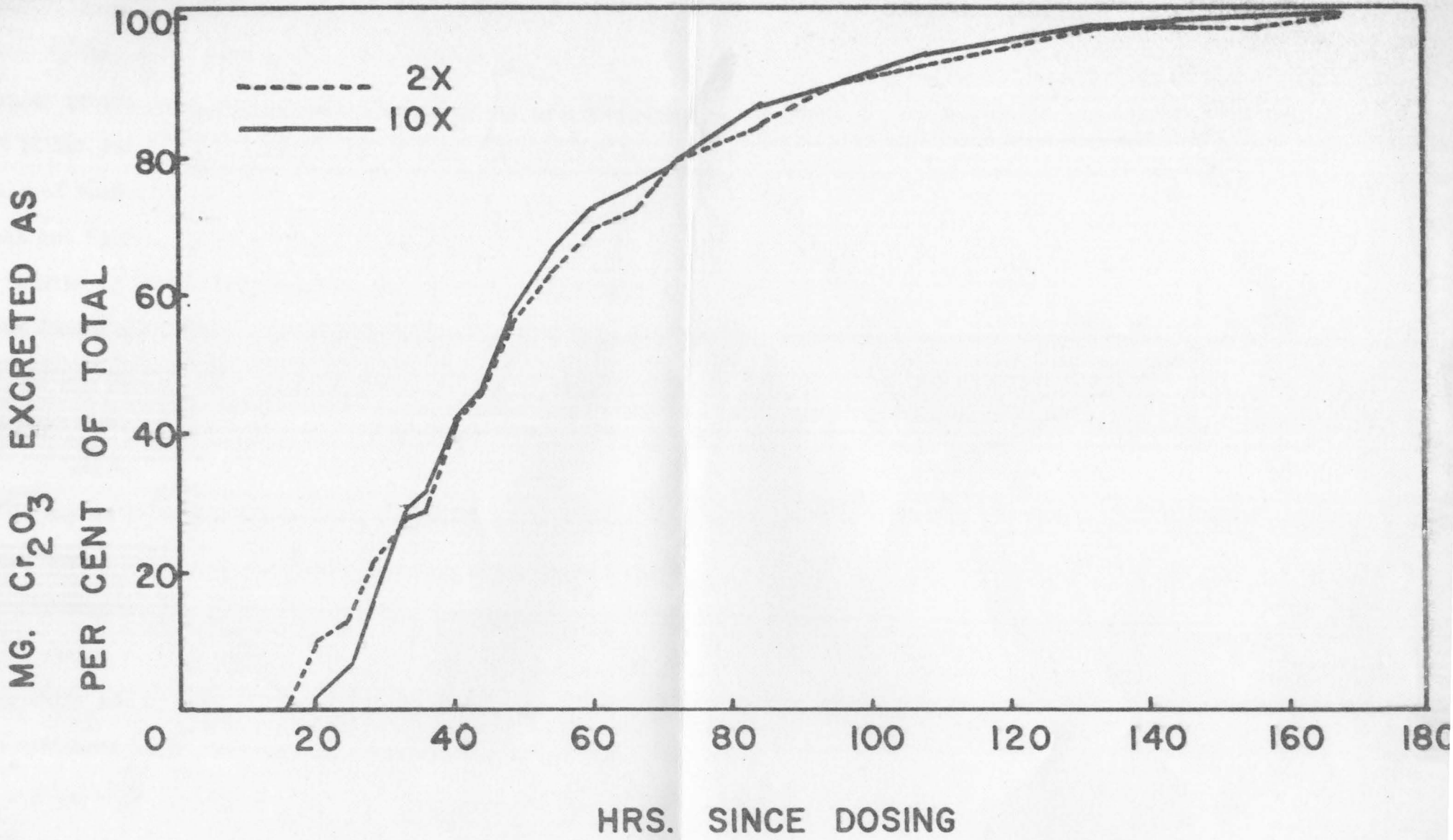

FIGURE 3. CUMULATIVE TOTAL OF THE Cr_2O_3 EXCRETED

DISCUSSION OF RESULTS

The results of this study show that increasing the frequency of feeding from twice to ten times daily significantly increased weight gains in dairy heifers. These findings were in agreement with those of Thomas and Mochrie[27] and Mochrie et al.[20] who reported that feeding dairy heifers four times daily resulted in significantly greater weight gains than when the same amount of feed was given either once or twice daily. It is interesting to note in the studies of Mochrie et al. that the milk production of first-calf heifers was not influenced by feeding frequency.

The results of the present study were also in agreement with the findings of Gordon and Tribe[15] who reported that increasing the frequency of feeding from once to eight times per day significantly increased the weight gains of sheep. These workers listed four possible explanations for the results which they obtained:

(1) "It may be that when a ration is divided into several small feeds spread over a long period of time the total surface area open to attack by microorganisms in the rumen might be larger and/or available for a longer period of time per unit of microbial activity than when the same quantity and quality of feed is given as one meal. In this way a more efficient coefficient of digestibility might be obtained."

In a limited study Gordon and Tribe[15] were able to confirm the above theory at least with respect to the digestibility of nitrogen. They also found the retention of nitrogen to be higher under frequent feeding conditions. On the other hand, the results of the present

study showed that the digestibility of the total ration as well as all of the proximate constituents except ether extract, was significantly higher for the animals fed twice daily than for the animals fed ten times daily. In work with fistulated steers[21] no detectable difference in *in vivo* cellulose digestion was found between animals fed two and ten times daily.

(2) "The work of Schalk and Amadon[25] and Balch[5] suggest that since food material passes into the omasum from the reticulum at a constant and not too rapid rate throughout the day, and since during a meal the heavier and more finely divided portion of the ration rapidly reached the reticulum, then under a system of small feeds this portion will pass on and into the abomasum in a short period of time. Therefore the loss due to fermentation processes will be minimal. However, if a large amount of food is ingested at one time it probably remains for longer in the rumino-reticular cavity, and this disproportionately greater delay will result in a large energy loss."

In this study no significant differences in the overall passage rate of feed were noted between the animals fed twice daily and those receiving their ration in ten equal feedings daily. This observation does not rule out the above possibility suggested by Gordon and Tribe, however, since it is possible than an increased rate of passage from the rumino-reticular cavity could be compensated for by a decreased passage rate through the lower gut.

There would appear to be a discrepancy between possibility (1) and (2) offered by Gordon and Tribe. When conditions in the reticulorumen

are such that microbial activity is higher or more concentrated it seems logical to assume that more of the feed energy is being wasted as a result of this increased activity and consequently less is available to the animal for productive purposes. According to possibility (1), such conditions would occur under a system of frequent feeding. On the other hand, possibility (2) suggests that the beneficial effects of frequent feeding are due, in part at least, to the decreased loss of energy as a result of bacterial fermentation.

In view of the increased weight gains made by the frequent-fed animals in the experiment of Gordon and Tribe as well as the present study, the second explanation appears to be the more feasible.

(3) "A completely different aspect is suggested by the third possibility. The even supply of substrate and the supposedly even production of metabolites that may occur under the frequent feed system may (a) give rise to an alimentary environment better suited to the growth and metabolism of microorganisms, and (b) it may enable the animal to utilize the metabolites more efficiently than under the single feed system where there may be a more rapid flooding of the tissues than is compatible with an optimal rate of utilization."

In view of this suggestion it is interesting to note that Finlayson and Baumann[13] reported that the inclusion of five percent urea in the diet of rats and fed once daily (within a two-hour period) was as effective in inhibiting growth as a diet containing 30 percent urea fed ad libitum. Since urea is a normal constituent of

forages, it is interesting to speculate whether giving small quantities of the forage at frequent intervals renders the urea present less toxic to the animal than when large amounts of the feed are given at infrequent intervals.

(4) "It is possible that the length of time spent ruminating under the two systems of management may be different and might, by the consequent difference in mechanical action upon the feed, result in differences in digestibility."

Gordon and Tribe (15) found in a limited investigation that sheep fed once daily spent more time ruminating than sheep fed eight times per day, however, as mentioned previously, the frequent-fed sheep exhibited higher coefficients of digestibility.

The data on rumination time obtained in the present experiment are directly opposite to that obtained in the above mentioned study. The rumination time per twenty-four hour period was significantly greater for the frequent-fed animals. However, the heifers fed twice daily ruminated for significantly longer periods of time during the daylight hours. As in the study of Gordon and Tribe, rumination time was found to be inversely correlated with digestibility.

In addition to the theories just discussed certain other possible explanations exist.

One involves the production of heat or the deposition by the animal of the heat produced during metabolic processes. In other words, is the heat increment of a ration influenced by frequency of feeding?

It seems logical to assume that when the ration is fed once or twice daily, large quantities of heat are produced following each feeding. The animal cannot efficiently utilize this heat for productive purposes and thus has to expend considerable energy getting rid of it. On the other hand, where the ration is given in small amounts at frequent intervals, heat production is presumably more uniform or constant. Under these conditions a more efficient utilization of the heat energy by the body cells could be effected or the animal would be able to dispose of the small excess of heat with a minimum expenditure of energy. In either situation more energy would be available for productive purposes.

There are reports in the literature which would appear to support the above. In experiments designed to check the specific dynamic effect of a basal and mixed diet, Richardson and Mason (24) found that when the mixed diet was divided into small portions and given at two-hour intervals, heat production was the same as when the basal was fed. Commenting on these experiments, Lusk (19) stated, "We may conclude from this evidence that if a mixed diet be so constituted as to conform to the exact needs of the tissues and be slowly introduced by absorption from the intestines, its specific dynamic action is virtually negligible, and that when there is great under-nutrition the gradual digestion, absorption, and deposition of fat added in excess of the body's requirements for energy, hay be accompanied by little or no manifestation of specific dynamic action."

In considering the possible factors affecting the thermogenic action of food, Hamilton (16) stated, "----The thermogenic action of food will vary depending upon the nature of the disposal of the absorbed nutrients. Thus any condition of the animal, or number of times fed per day, or amount of feed at any one time, or composition of the feed which will result in a more efficient utilization of the absorbed nutrients, will invariably result in a lower thermogenic effect."

Still another possible explanation is suggested by data obtained with fistulated steers by Moore (21). In this study it was observed that the pH of the rumen contents of frequent-fed steers was consistently lower than those of steers fed twice daily.

Investigations conducted by Watt and Werkman (28) and also by Reynolds (23) indicate that under extremely acid conditions larger quantities of alcohols are produced from bacterial fermentation than under less acid conditions. Apparently the microorganisms, in order to prevent self-destruction in a completely acidified medium, produce the higher molecular weight acids and liberal amounts of alcohols instead of the lower molecular weight acids. Since a lesser amount of the higher molecular weight acids can be produced from a given amount of substrate and the alcohols produced does not acidify the medium, conditions for microbiological growth and activity can be maintained.

Since a fermentation medium characterized by a low PH is conductive to the production of alcohols, and since alcohols are not as highly oxygenated as are acids, and thus contain significantly greater amounts of potential energy, the possibility exists that the frequent-fed animals were obtaining greater porportions of energy for productive purposes due to a shift in rumen fermentation.

The precise explanation for the increased weight gains obtained with the frequent-fed animals in this study is still obscure. It may be that a combination of several of the factors discussed is involved. On the other hand, a factor or factors yet to be uncovered may hold the key to the riddle.

Heart rate and rectal temperature measurements taken in connection with this study showed that both of these were significantly higher in the frequent-fed heifers than in the heifers fed twice per day. This was to be expected since several workers have shown that heart rate and body temperature increase immediately after the consumption of feed. Subsequent studies by Rakes (22) have confirmed these observations on body temperature.

Blaxter et al. (7) have discussed frequent feeding with respect to the conduct of digestibility trials. They concluded that frequent feeding at regular intervals is desirable and would minimize the errors involved in such trials. They also conclude that the rate of fecal production is not constant but depends on the frequency of feeding and

the passage of food. "Foods which pass quickly and are given at infrequent intervals give rise to considerable variation in rate; foods which are given at frequent intervals and pass slowly give relatively stable rates."

It is quite obvious that if such differences in weight gain as found in this and other studies can be obtained by controlling the frequency of feeding, then more attention must be exercised in further nutritional work where weight gain is the primary criterion of measurement to control this aspect. Also it becomes necessary to consider earlier ruminant nutrition research with this point in mind.

The information from such studies could be of considerable pracitcal importance since it would be comparatively easy to design automatic feeders which would feed livestock at periodic intervals throughout the day.

SUMMARY

Twelve dairy heifers (eight Holsteins and four Guernseys) weighing approximately 300 to 500 pounds were used in a single reversal trial to study the effect of feeding equalized intakes of feed two and ten times daily on body weight gain, nutrient digestibility, rate of food passage, and certain physiological activities. Chopped alfalfa-orchard grass hay of medium quality was the only feed used. The animals were brought up to a maximum feed intake during a twenty-one day preliminary period, and this level of intake was maintained during the two, fifty-day experimental periods which followed.

Body weights were taken on three successive days at the beginning and end of each experimental period and at ten-day intervals in between.

Conventional digestion trials employing all animals were conducted during the latter part of each experimental period. Rumination time was recorded for all animals for three twenty-four hour periods during each digestion trial. Rate of food passage measurements were taken in conjunction with the second digestion trial. Only three animals from each treatment group were used in these measurements.

Each day throughout the experiment (excluding a brief preliminary period at the beginning), the heart rate and rectal temperature of each animal was recorded.

Frequent feeding significantly increased weight gain (P 0.01)

and significantly decreased feed digestibility (P 0.01). The animals on frequent feeding ruminated significantly longer per twenty-four hour period than did the animals fed twice daily (P 0.01). It was found, however, that the animals fed twice daily spent significantly more time ruminating during the daylight hours than did the animals fed ten times daily (P 0.05). There was no significant difference in the rate of food passage between the two times and the ten times-a-day feeding schedule.

Heart rate and body temperature measurements were significantly higher in the animals fed twice daily. It is indicated that these differences were due to the times these measurements were taken relative to feeding rather than to frequency of feeding.

Possible reasons for these results are discussed in view of the existing literature and the practical significance of the study are mentioned.

CONCLUSIONS

Under the conditions and limitations of this study the following conclusions appear justified:

(1) Increasing the frequency of feeding from two to ten times per day can be expected to significantly increase body weight gains of the young ruminant animal.

(2) Such a practice can also be expected to decrease the digestibility of the ration.

(3) It is indicated that frequency of feeding has little or no effect on the rate of food passage in the ruminant.

(4) Increasing the number of times per day that the animal is fed results in an increase in total rumination time, and the pattern of rumination resembles somewhat that observed in the grazing animal in that most of it occurs at night when the animal is not being fed.

(5) In view of the effect of frequency of feeding on weight gain, more attention must be exercised in future nutritional work where weight gains are the primary criterion of measurement to control this aspect. Also, it becomes necessary to consider earlier ruminant nutrition research with this point in mind.

(6) The livestockman could greatly increase the efficiency of feed utilization of his animals by increasing the number of times per day that he feeds. Although under present conditions the increased labor

requirements for such a practice would make it impractical, it would appear to be a comparatively easy task to design an automatic device for feeding at specified intervals throughout the day which would greatly decrease the labor requirements.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his sincere appreciation and gratitude to the following persons for their invaluable assistance and supervision throughout the conduct of the work reported in this thesis:

Dr. W. A. Hardison, for complete co-operation, invaluable guidance, and unselfish devotion of time given toward the final completion of this project.

Dr. G. C. Graf, for making the facilities available and complete co-operation throughout the entire experiment.

The Ralston Purina Company, for the financial assistance given in the form of a fellowship to the author.

Dr. R. W. Engel and Dr. W. E. C. Moore, for co-operation and assistance given throughout the project.

Dr. N. R. Thompson and C. Y. Kramer, for advice given on the statistical aspects of the problem.

Professor P. M. Reaves, for advice given on the project from time to time.

and , for assistance in the conduct of the trial and in the chemical determinations.

, for assistance in reproducing the graphs,

, for the typing of the manuscript.

BIBLIOGRAPHY

1. Annual Report: Tenn. Agr. Expt. Sta. 55. 1945.

2. Annual Report: Wis. Agr. Expt. Sta. 107. 1930-31.

3. Association of Agricultural Chemists, Official Methods of Analysis, 8th Ed., Washington, D. C. 1955.

4. Bohsteldt, G. The Wisconsin Self-Feeder for Hogs. Wis Agr. Expt. Sta. Bull. 419. 1931.

5. Balch, C. C. Factors Affecting the Utilization of Food by Dairy Cows, I The Rate of Passage of Food through the Digestive Tract. Brit. J. Nutr., 4: 361 1951.

6. Blaxter, K. L. The Normal Variation in the Heart Rate of Dairy Cows. Vet. J., 99: 2. 1943.

7. Blaxter, K. L., Graham, N. Mc C., and Wainman, F. W. Some Observations on the Digestibility of Food by Sheep, and on Related Problems. Brit. J. Nutr., 10: 69. 1956.

8. Brown, G. A. and Blakeslee, L. H. Self-Feeding Versus Hand Feeding for Fattening Lambs. Mich. Agr. Expt. Sta. Spec. Bull. 303. 1940.

9. Castle, E. J. The Rate of Passage of Foodstuffs through the Alimentary Tract of the Goat. Brit. J. Nutr., 10: 15. 1955.

10. Cochran, W. G. and Cox, G. M. Experimental Designs. 1st Ed. John Wiley and Sons. 1950.

11. Darlow, A. E. Fattening Western Lambs. Okla. Agr. Expt. Sta. Bull. 228. 1935.

12. Dawson, J. R. and Kopland, D. V. Once-A-Day Versus Twice-A-Day Feeding for Dairy Cows. Mont. Agr. Expt. Sta. Cir. 830. 1949.

13. Finlayson, J. S. and Baumann, C. A. Responses of Rats to Urea and Related Substances. J. Nutr., 59: 211. 1956.

14. Forbes, E. B., Kriss, M. and Swift, R. W. Fasting Metabolism of Cattle as a Base Value of Heat Production Determination of Net Energy of Feeding Stuffs. J. Agr. Res., 43: 1003. 1931.

15. Gordon, J. G. and Tribe, D. E. Importance of Frequency of Feeding to Sheep. Brit. J. Nutr., 6: 89. 1952.

16. Hamilton, T. S. Factors Affecting the Thermogenic Action of Food. Report of the Conference on Energy Metabolism. Penn. State. 1935.

17. Ingraham, A. A. Utilizing Self-Feeding Methods for Fattening Lambs on Sugar Beet by-Products and Other Home-Grown Feeds. Wyo. Agr. Expt. Sta. Bull. 257. 1942.

18. Jorden, P. S. and Peters, W. H. Fattening Lambs. Minn. Agr. Expt. Sta. Bull. 222. 1930.

19. Lusk, G. The Specific Dynamic Action. J. Nutr., 3: 519. 1931.

20. Mochrie, R. D., Thomas, W. E. and Lucas, H. L. Influence of Frequency of Feeding Equalized Intakes on Animal Response. J. An. Sci., 15: 1256. (Ab.) 1956.

21. Moore, W. E. C. Unpublished data. Va. Agr. Expt. Sta. 1956.

22. Rakes, A. H. Unpublished data. Va. Agr. Expt. Sta. 1956.

23. Reynolds, H., Mc Cleskey, C. S., and Werkman, C. H. Dissimilation of Sucrose by Shigella Paradysenteriae (Var. Sonnei). J. Infect. Dis., 55: 207. 1934.

24. Richardson, H. B. and Mason, E. H. The Effect of Fasting in Diabetes as Compared with a Diet Designed to Replace the Foodstuffs Oxidized During a Fast. J. Biol. Chem., 57: 587. 1923.

25. Schalk, A. F. and Amadon, R. S. Physiology of the Ruminant Stomach. N. Dak. Agr. Expt. Sta. Bull. 216. 1928.

26. Schurch, A. F., Lloyd, L. E., and Crampton, E. W. The Use of Chromic Oxide as an Index for Determining the Digestibility of a Diet. J. Nutr., 4: 629. 1950.

27. Thomas, W. E. and Mochrie, R. D. Effect of Frequency of Feeding Equalized Intakes of Feed on Growth of Dairy Heifers. Proc. Assoc. Southern Agr. Workers, 53rd Conv., p. 123. 1956.

28. Watt, D. and Werkman, G. H. Modification of the Enzyme System of Micrococcus Pyogenes. Arch. of Biochem., 31: 383. 1951.

The vita has been removed from the scanned document

APPENDIX

TABLE 19

Total Body Weight Gains of

Animals During Period 1 and Period 2

Animal Number	Period 1		Period 2	
	2X	10X	2X	10X
1949		58	39	
1962	54			66
1958	54			63
1940	43			57
1975		61	33	
1971	28			34
1984		48	6	
1951		71	14	
953	15			-28
967	22			48
969		48	-15	
986		39	1	
Averages	36	54	13	40

Total Gains for Animals on 2X Feeding .. 294 lbs.

Total Gains for Animals on 10X Feeding .. 565 lbs.

TABLE 20

The Average Number of Pounds of Feed Required for One Pound of Gain During Period 1 and Period 2

Animal Number	Period 1		Period 2	
	2X	10X	2X	10X
1949		12.1	17.9	
1962	12.9			10.6
1958	13.0			11.1
1940	16.3			12.3
1975		11.2	21.2	
1971	17.9			14.7
1984		10.4	83.3	
1951		9.9	50.0	
953**				
967	18.1			8.3
969**				
986		10.2	400.0	
Averages	15.6	10.8	114.4	11.4

Average for Animals on 2X Feeding .. 65.0

Average for Animals on 10X Feeding .. 11.1

** Animals Lost Weight During Trials

TABLE 21

Average Heart Rates of

Animals During Period 1 and Period 2

Animal Number	Period 1		Period 2	
	2X	10X	2X	10X
1949		71.4	62.3	
1962	64.0			75.8
1958	60.5			77.3
1940	65.1			77.7
1975		66.9	62.3	
1971	59.4			76.8
1984		63.4	60.6	
1951		68.9	64.8	
953	60.3			79.2
967	63.2			76.0
969		69.7	61.7	
986		68.6	61.5	
Averages	61.9	68.2	62.2	77.1

Overall Average 2X .. 62.1

Overall Average 10X .. 72.7

TABLE 22

Average Rectal Temperatures

of Animals During Period 1 and 2

Animal Number	Period 1		Period 2	
	2X	10X	2X	10X
1949		101.8	100.9	
1962	101.6			101.9
1958	101.3			101.9
1940	101.4			101.9
1975		102.0	101.0	
1971	101.3			101.7
1984		101.8	101.2	
1951		102.0	101.1	
953	101.3			101.8
967	101.2			101.8
969		101.8	100.9	
986		101.8	100.9	
Averages	101.4	101.9	101.0	101.8

Overall Average 2X .. 101.2

Overall Average 10X .. 101.9

TABLE 23

Average Rumination Time (Per 24-hour Period)

of Animals During Trial 1 and Trial 2

Animal Number	Period 1		Period 2	
	2X	10X	2X	10X
1949		446	387	
1962	390			401
1958	372			428
1940	443			357
1975		543	369	
1971	360			360
1984		390	325	
1951		487	416	
953**				
967	331			269
969		484	304	
986**				
Averages	379	470	360	363

Average For Animals on 2X Feeding .. 370

Average For Animals on 10X Feeding .. 417

** Eliminated Due to Temporary Abnormality

TABLE 24

Average Rumination Time (Per 24-hour Period)

of Animals Between 7:00 a.m. and 6:00 p.m. During

Trial 1 and Trial 2

Animal Number	Period 1		Period 2	
	2X	10X	2X	10X
1949		128	208	
1962	296			268
1958	206			159
1940	242			200
1975		200		
1971	200		204	129
1984		68		
1951		200	203	
953**			210	
967	246			102
969		88	159	
986**				
Average	238	137	197	172

Average For Animals on 2X Feeding .. 218

Average For Animals on 10X Feeding .. 155

** Eliminated Due to Temporary Abnormality

TABLE 25

Percentage of Total Cr_2O_3

Excreted at Various Intervals

After Dosing

Hrs. Since Dosing	2X Feeding				10X Feeding			
	1949	1984	986	Avg.	1940	1971	953	Avg.
12								
16	5.0			1.7				
20	30.8			10.3			9.4	3.1
24	30.8	4.9	3.6	13.1		9.0	13.7	7.6
28	38.7	12.7	9.2	20.2	7.4	18.7	24.7	16.9
32	43.9	20.4	19.9	28.1	21.3	27.9	39.2	29.5
36	47.8	20.4	19.9	29.4	32.8	28.5	39.2	33.5
40	48.7	35.6	44.1	42.8	34.2	41.1	52.2	42.5
44	48.7	45.2	44.1	46.0	47.1	41.1	52.4	46.9
48	68.5	47.4	52.2	56.0	55.6	59.5	57.4	57.5
54	72.8	58.1	60.5	63.8	67.3	68.0	64.2	66.5
60	76.5	63.2	69.0	69.6	73.9	72.1	71.0	72.3
66	77.6	64.4	74.7	72.2	76.2	73.6	76.8	75.5
72	84.7	74.2	78.9	79.3	79.3	78.4	76.8	78.8
84	84.7	84.5	86.0	84.4	86.8	85.6	88.3	86.9
96	92.8	86.8	91.3	90.3	90.3	90.0	91.5	90.6
108	95.5	90.0	93.8	93.1	92.8	93.8	94.4	93.7
120	97.4	92.8	96.1	95.4	95.1	95.6	96.6	95.8
132	97.4	97.7	97.6	97.6	95.1	97.5	98.6	97.1
144	100.0	97.7	98.2	98.6	92.6	99.3	100.0	98.9
156		97.7	98.2	98.6	97.6	100.0		99.2
168		100.0	100.0	100.0	100.0			100.0

TABLE 26

Percentage of the Total

Number of Stained Particles

Excreted at Various Intervals

After Dosing

Hrs. Since Dosing	2X Feeding				10X Feeding			
	1949	1984	986	Avg.	1940	1971	953	Avg.
12								
16								
20	7.9	9.5		5.8			7.6	2.5
24	16.3	13.2		9.8	13.1	11.1	13.0	12.4
28	19.2	21.6		13.6	13.7	13.2	16.0	14.3
32	27.0	21.6	6.3	18.3	15.5	20.0	18.4	18.0
36	31.1	32.7	10.7	24.8	23.4	21.9	23.6	23.0
40	31.8	46.5	19.5	32.6	31.8	30.7	27.3	29.9
44	32.6	53.5	19.5	35.2	35.8	31.5	31.4	32.9
48	39.9	61.8	29.6	43.8	37.5	41.9	37.6	39.0
54	44.3	69.4	38.2	50.6	48.0	51.3	47.0	48.8
60	50.0	74.5	44.1	56.2	51.5	58.6	52.9	54.3
66	61.2	77.6	52.4	63.7	56.9	65.3	60.0	60.7
72	67.2	88.8	72.5	76.2	60.2	66.1	60.0	62.1
84	67.2	92.6	87.8	82.5	69.8	74.8	73.3	72.6
96	77.0	97.4	88.4	87.6	78.5	83.2	76.1	79.3
108	83.0	100.0	93.8	92.3	85.7	90.4	81.8	86.0
120	88.6		97.1	95.2	88.2	94.0	86.4	89.5
132	88.6		100.0	96.2	88.2	100.0	94.5	94.2
144	99.4			99.8	97.0		100.0	99.0
156	100.0			100.0	1000			100.0
168								