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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XXXVI. Interrelations Between Temperatures of Rumen (At Various Depths), Rectum, Blood, and Environmental Air; and the Effects of an Antipyretic, Feed and Water Consumption

S. BRODY, H. E. DALE, AND R. E. STEWART

Missouri Agricultural Experiment Station and the United States Department of Agriculture Cooperating

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ORIENTATION

The cow rumen (the largest of the 4-chambered stomach) is a huge (up to 40 gallons) fermentation vat in which occur digestive and synthetic processes (syntheses of B vitamins, amino acids, short-chain fatty acids) of the greatest nutritional and economic importance.[1]

These, like other fermentation processes, are associated with anaerobic heat production. Ninety-nine percent of the bacteria isolated from rumen content above the level of contamination were obligate anaerobes[2]. Being anaerobic, the heat production *in the rumen proper* (as distinguished from the overall oxidative heat production into which the rumen products enter) is not included in the conventional indirect calorimetry-oxygen consumption method of heat production measurements. This is particularly true of the anaerobic production of the huge amounts of methane with correspondingly large but quantitatively unknown energy exchanges. In other words, the overall heat production in cattle as determined by indirect calorimetry—by the oxygen consumption method—is probably much less than it would be by direct calorimetry, including rumen fermentation.

Attempts were therefore made to compute the rumen heat production, or the "cost of rumen digestion." The estimates are many,[3] ranging between 6 and 12 percent of the heat value of the ingested feed. There are, however, no direct measurements of heat production.

Rumen heat is useful in cold weather to help keep the animal warm. In hot weather, however, when the thermal gradients and the rates of heat dissipation are severely depressed, the rumen heat increases the animal's heat stress. The high rumen temperature may, moreover, interfere with the digestive and synthetic processes in the rumen and thus perhaps lead to the malnutrition associated with tropical deterioration of European-evolved cattle. It, therefore, seemed appropriate, as part of our climatic project, to

*Author sequence is alphabetical.

investigate the temperature relations in the rumen, and, as far as possible, to investigate the heat-exchange relations and thermal gradients between the body proper and the rumen, and their effects on the biosynthetic processes in the rumen as determined by vitamin B production. This bulletin reports on the method of measuring rumen temperature—how it is affected by feed and water intake, by administration of an antipyretic, and by the usual diurnal temperature fluctuations of the environment in various climatic regions.

METHODS

The data were obtained in the temperature controlled Psychroenergetic Laboratory under constant temperature (about 65° F.) and also under several diurnally-variable conditions (Figs. 6 and 7 in this bulletin, also Figs. 1 to 3 in Res. Bul. 578), to be discussed presently.

Rectal temperatures were recorded from a copper-constantan thermocouple inserted to a depth of 6 inches. Rumen temperatures were measured at three levels or heights, 6 inches apart, including a total distance of 18 inches (Figs. 1 to 4).

The opening in the rumen was made by the method of Ebert, Roseboom, and Dale.[4] The tip of the probe rested in the ventral sac of the rumen several inches to the right of the midline. Unlike rumen fistula, the stab here made with the probe in place closed the rumen surface so there was no contact with air, no leakage of gas, and no interference with the normal rumination processes.

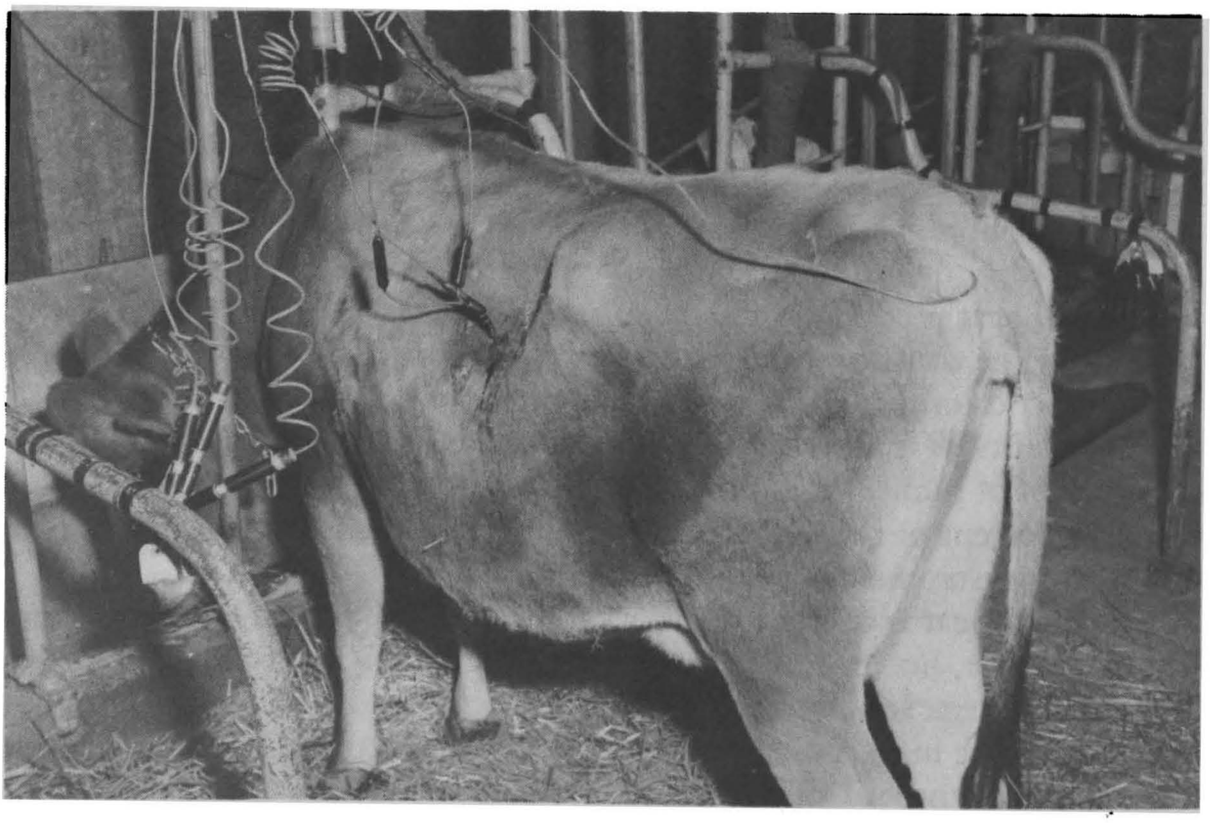


Figure 1—Cow with thermocouples in rectum and rumen.

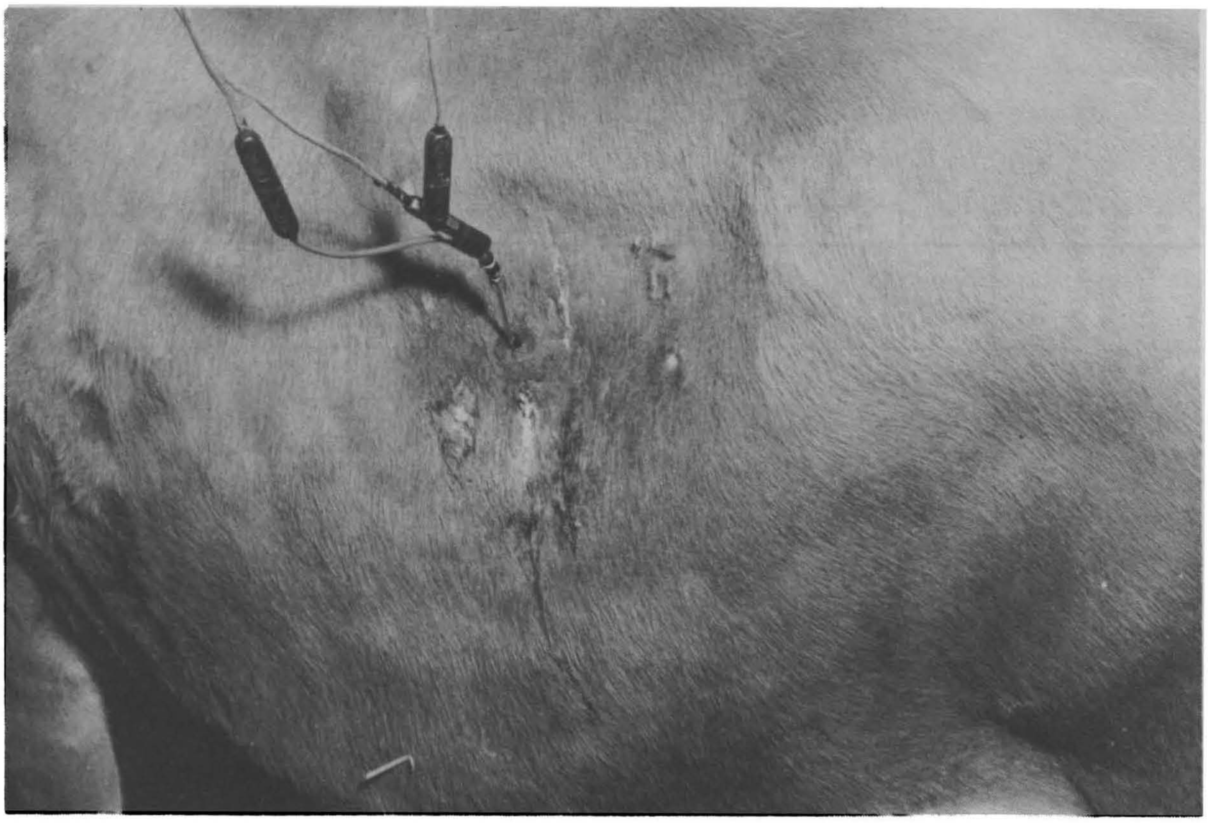


Figure 2—Close-up of the probe with its three thermocouples inserted in the ventral sac of the rumen through a small stab wound.

The apparatus consisted of a thermocouple probe and recording potentiometer. The probe was made from a stainless steel artificial insemination tube, 18 inches long and about $^3/_{32}$ inches outside diameter. Thermocouples made of 30-gauge (B&S) copper-constantan wire were brought from within to the surface of the probe at the tip, 6 inches from the tip, and 12 inches from the tip; these thermocouples were soldered into position on the probe (Fig. 2).

The thermocouple leads from the probe were brought out to a 16-point, 4-minute cycle, electronic-balance type Brown recording potentiometer calibrated from 0° to 50° C. The smallest scale division was 0.2° C. and could easily be read to 0.1° C. The calibrated accuracy of the potentiometer, 0.02 millivolts, corresponded to plus or minus 0.5° C. The Brown potentiometer was calibrated by the use of a Leeds & Northrup laboratory standard potentiometer and occasionally checked against a Bureau of Standards mercury thermometer. The overall precision of the temperature measurements was 0.2° C.

RUMEN-RECTAL TEMPERATURE GRADIENTS AND EFFECT OF WATER INTAKE[5] ON RUMEN AND RECTAL TEMPERATURES

The data, plotted in Fig. 3, were obtained in the climatic chamber at temperatures of 62° to 65° F. The rumen temperature was measured at three levels. The normal top-to-bottom (18-inch distance) rumen temperature difference was 3° F. (Fig. 3). The normal midpoint rumen temperature was about 3° F. above the rectal temperature. Administration by stomach tube of 14 pounds water of the same temperature as the environmental air (about

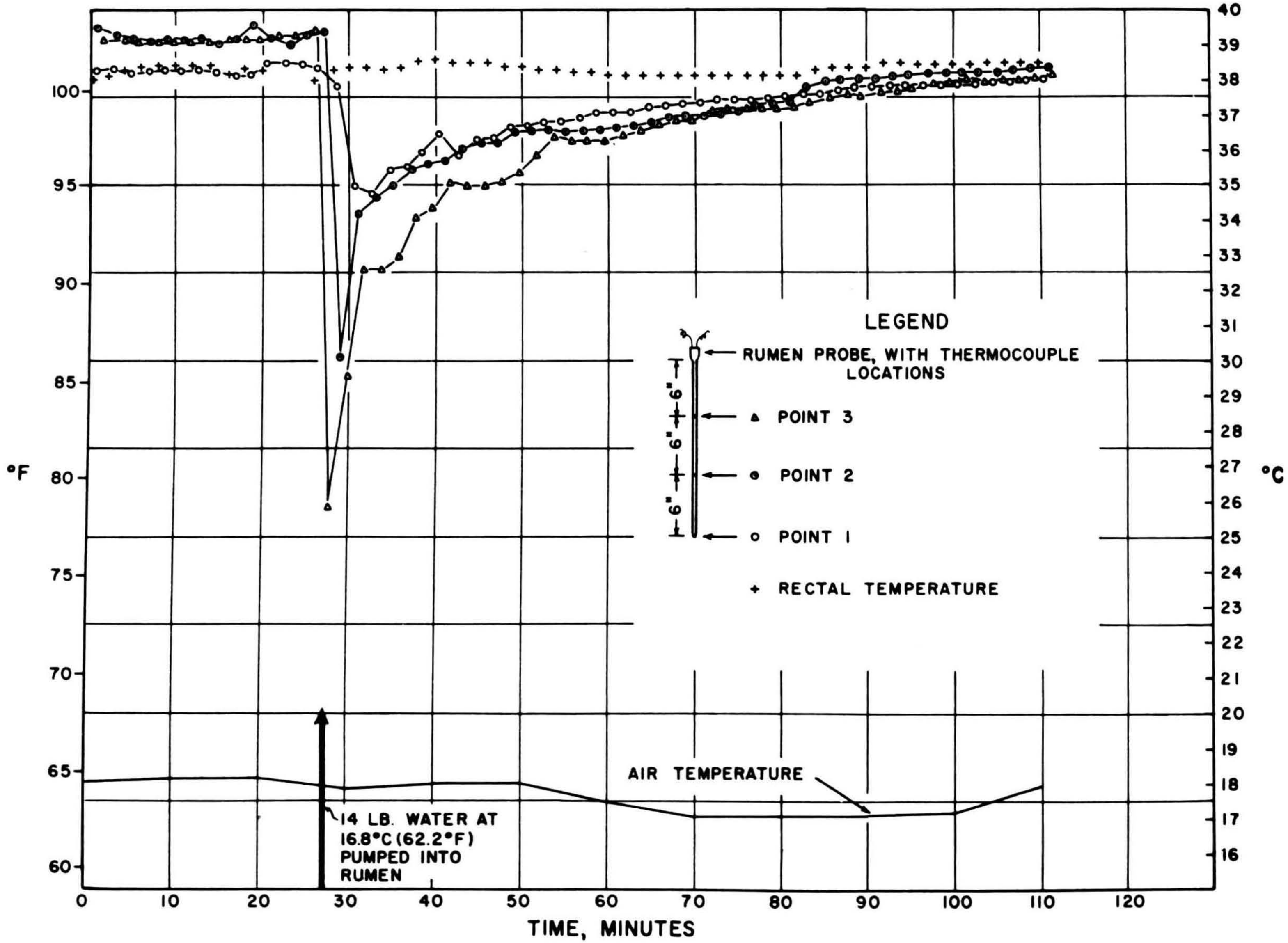


Figure 3—Changes in rectal temperature, and rumen temperatures at three levels, following administration of 14 lb. water at 62.2° F (the same as the environmental temperature).

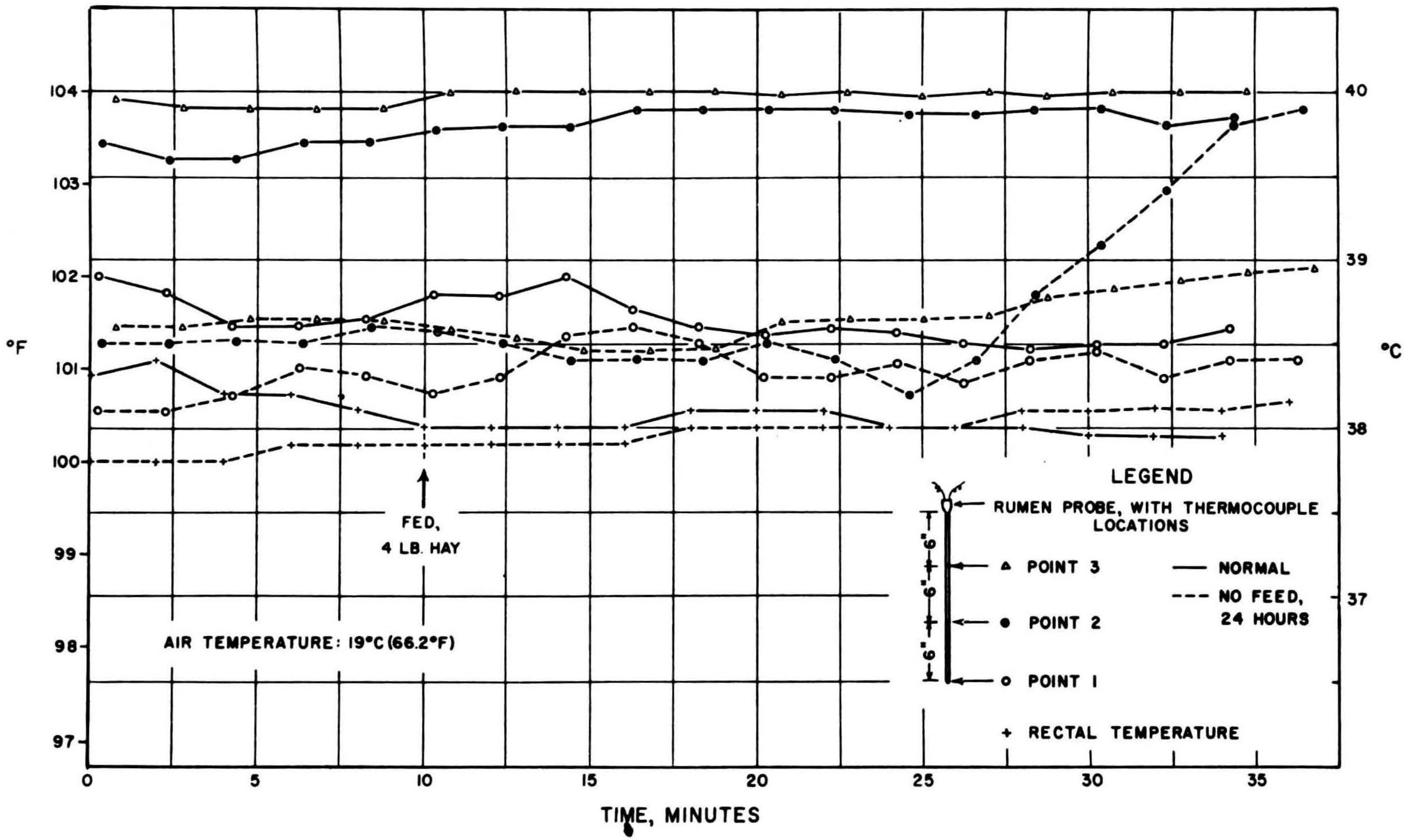


Figure 4—Rectal temperature and rumen temperatures at three levels following a 24-hour fast (broken curves) and when normally fed (continuous curves). The feeding and fasting rectal temperatures (crosses, the lowest curves) do not differ substantially; but the upper (triangles) and middle rumen (circles) temperatures are much higher during feeding than during fasting.

65° F.) sharply reduced the rumen temperature from the original 101° to 104° F. down to 80° to 90° F. (depending on the rumen level). About two hours were required for the rumen temperature to climb back to 101° F. While the rumen temperature thus fluctuated, the rectal temperature remained stable.

EFFECT OF FEEDING AND FASTING ON RUMEN AND RECTAL TEMPERATURES

Fig. 4 shows that withholding feed for 24 hours reduced the 4° F. rumen-rectal temperature difference to 1.5° F. On feeding 4 pounds hay to the fasted cow, the middle rumen temperature increased from the pre-feeding level of 101° F. to feed level of almost 104° F. within 25 minutes after beginning to eat. While the rumen temperature thus fluctuated the rectal temperature remained practically constant.

Summing up the above two sections, the rumen temperature responds much more sensitively to feeding, fasting, and water intake than the rectal temperature. The maximal rumen temperature is almost 4° F. above the rectal temperature. This substantiates the idea that the anaerobic heat production in the rumen can perhaps be measured by the difference between total heat elimination by direct calorimetry (including rumen heat) and heat production by the body proper, not including the anaerobic rumen heat, as measured by the oxygen consumption method.

BLOOD TEMPERATURE IN RELATION TO RUMEN AND RECTAL TEMPERATURE

Blood temperature was measured with a copper-constantan thermocouple fixed in the tip of a 72-inch polyethylene catheter.

The catheter was introduced into the right jugular vein of a 3-year old Jersey (#574) fasted 24 hours through a 12 gauge needle inserted at a point 9 inches below the ramus of the mandible and 28 inches above the olecranon of the right ulna. It was first estimated that the catheter would have to be passed about 30 inches before reaching the right ventricle. The following temperatures of the blood were observed at various depths:

	Mean Temp., °F		*Standard Deviation*
6 inches deep	98.82	±	0.463
12 " "	98.87	±	0.391
18 " "	99.54	±	0.432
24 " "	100.27	±	0.542
30 " "	100.40	±	0.545
36 " "	100.33	±	0.473

The catheter thermocouple was kept for 15 minutes at a depth of 60 inches;* thermocouples were kept at the same time in the rectum and rumen with the following comparative temperature levels:

	Mean Temp., °F		*Standard Deviation*
Blood	100.18		
Rectal	100.99		
Lower Rumen, P_1	100.89	±	0.20
Upper Rumen, P_2	103.14	±	0.07
Environmental Air	61.17	±	1.40

The rumen temperature—especially the upper part—is seen to be above the rectal and blood temperature, again substantiating the idea that heat is being produced in the rumen which could, with appropriate equipment, be measured independently of the oxidative heat production in the body proper.

To sum up this section, the temperature of the jugular vein blood increased by 1.4° F. on moving down to the thorax. Venous blood temperature, measured over a 15-minute interval, remained constant at 0.7° F. below the lowest mean rumen temperature. Rectal temperature was slightly above that of the lower rumen contents. The temperature of the upper rumen was 2.3° F. above the temperature of the lower rumen, 3° F. above the blood temperature, and 2.2° F. above the rectal temperature.

EFFECT OF ANTIPYRINE ON RUMEN AND RECTAL TEMPERATURES

It seemed instructive to find out how an antipyretic affects the rumen-rectal temperature relations.

A 900-pound Jersey cow (#518) was injected intravenously 10.2 gm antipyrine** at 60° F. The results are graphed in Fig. 5. Injection is seen to be followed, within minutes, by a slight decline in rectal temperature. About 70 minutes after injection, the cow began shivering. The shivering continued for about one hour (until 130 minutes after injection) accompanied by a 1.5° F. rise in rectal temperature.

As before, rumen and rectal temperature tend to vary together.

The time sequences in rise in rectal and rumen temperatures, however, were opposite to those in the preceding feeding and watering experiments (Fig. 3).

* Although it was hoped that this would place the thermocouple in the posterior vena cava, the arrangement of the entering vessels and the absence of temperature change make it seem more probable that the thermocouple was in the right ventricle and the surplus catheter was coiled in the anterior vena cava and the right ventricle.

**Antipyrine, an antipyretic, is supposed to accelerate heat dissipation by cutaneous vasodilation by acting on the heat-regulating centers of the nervous system.

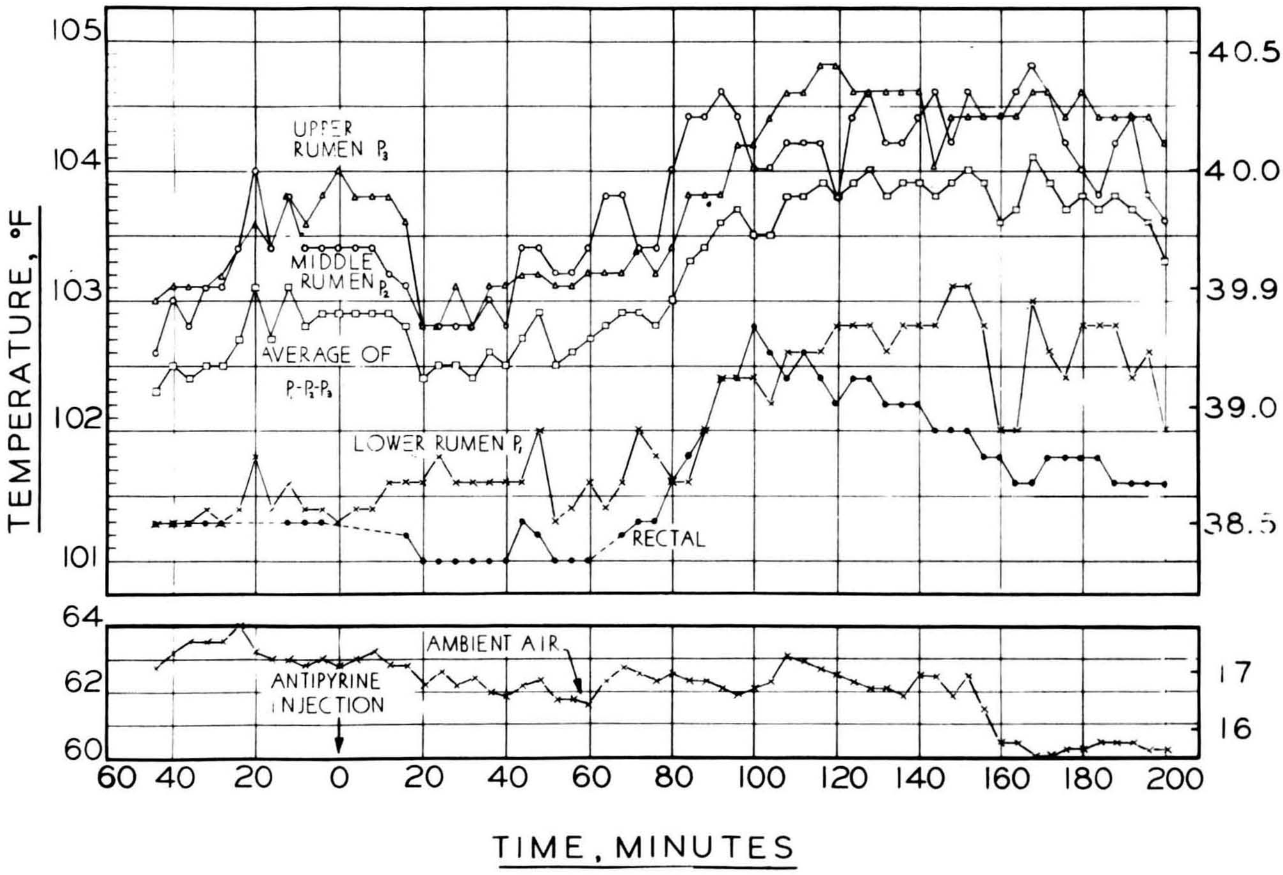


Figure 5—The effect of antipyrine administration on rectal and rumen temperatures at three levels.

In the feeding and watering experiments, the rumen temperature rose first, followed by ("caused") a rise in rectal (and blood) temperature. In the present antipyretic experiments, the rectal (and blood) temperature rose first, followed by ("caused") a rise in rumen temperature.

This result again substantiates the idea that heat is produced anaerobically in the rumen (independently of the overall aerobic oxidation of the body proper) and thus, perhaps, can be measured by difference between the indirect oxygen-consumption method, and the direct total-heat dissipation method. This result also suggests that the rise in rumen temperature may limit feed consumption and milk production in hot weather.

EFFECT OF FOUR REGIONAL CLIMATIC CONDITIONS ON RUMEN AND RECTAL TEMPERATURES

The temperatures of the upper, middle, and lower rumen, and also of the rectum, were measured in the Jersey cows when they were housed in a climatic chamber simulating the diurnal temperature rhythms of four climatic conditions: "Midwest Cold", diurnal range 10° to 40° F; "Midwest Normal", 40° to 70° F; "Midwest Hot", 70° to 100° F; "Imperial Valley", 60° to 110° F.

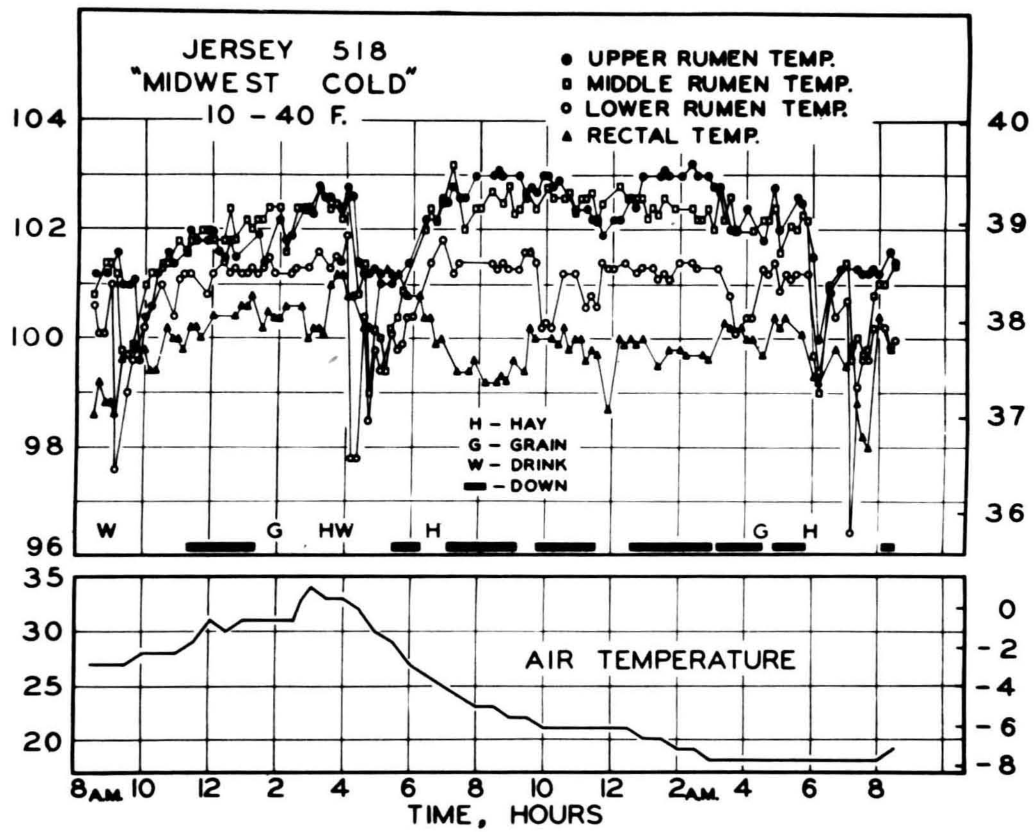
The results of the statistical analyses of the data are presented in self-explanatory Table 1 (means and standard errors of rumen and rectal temperature of two cows); Table 2 (analysis of variance of rectal temperature); and in Tables 3a and 3b (means and variance of each cow separately). The graphic results for each cow and climatic conditions are given in Figs. 6a to d and 7a to d.

The rectal and rumen temperatures vary generally together, except in the case of the "Midwest Cold" condition, where they are somewhat out of phase in their cycles. The temperatures seem to peak at 2 to 6 p.m. and at 3 to 6 a.m., the 2 to 6 p.m. peak being generally the highest.

The analysis of variance results, as shown in Table 2, seem to indicate that rectal temperatures are affected by environmental temperatures; and that rectal temperatures vary significantly during a 24-hour period.

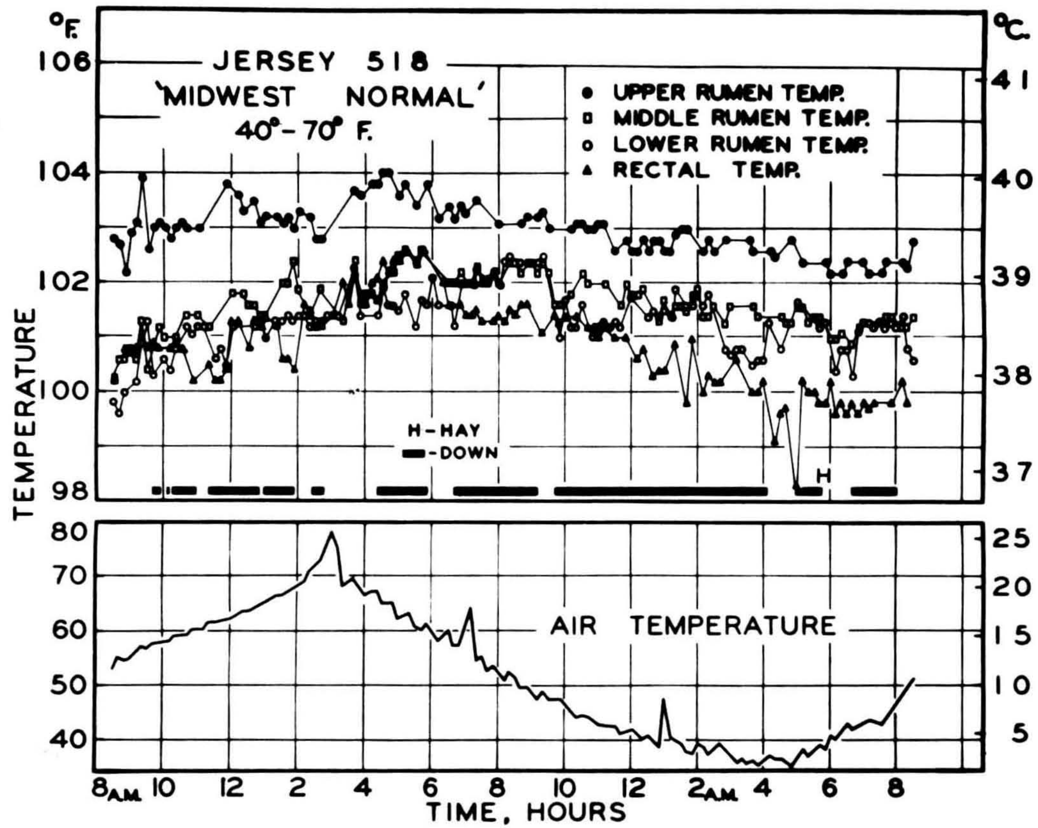
The sections of Table 2 headed "Four Climatic Conditions" include the data from all four climatic conditions. The sections headed "Three Climatic Conditions" do not include the data from the "Midwest Cold" condition.

The reason that the "Midwest Cold" condition was not included is that in comparing the graphs of rectal and rumen temperatures, it was found that "Midwest Cold" graphs tended to be out of phase with one another—that is, in the three other conditions, the peaks and troughs of the rectal temperatures closely coincided with the peaks and troughs of the rumen temperatures, but in the "Midwest Cold" conditions they were out of phase with one another. The drop in "F" values indicates that an inordinate amount of variation could be attributed to the "Midwest Cold" condition. However, the rise in the "F" value among times of day for Jersey cow 518 cannot be explained. It could be due to a great many things. The data in Tables 1 and 2 cannot be assumed statistically representative, since they were derived from only two relatively inferior dry Jersey cows, but they indicate approximate behavior of the dairy cow under the given conditions.



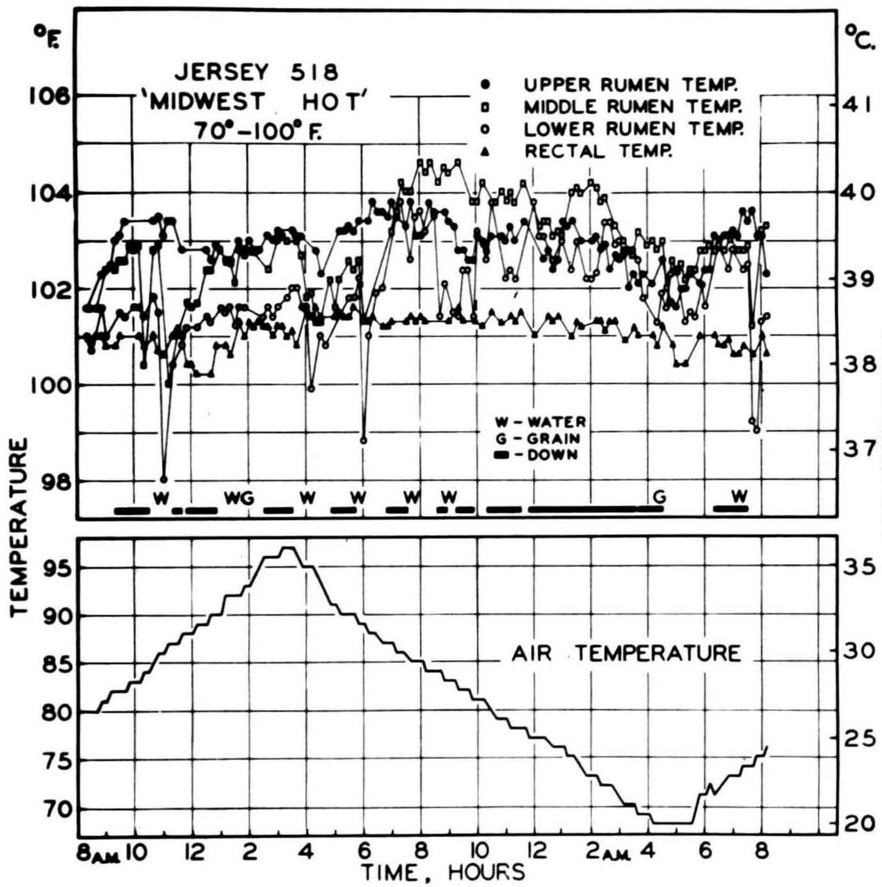
JERSEY 518
"MIDWEST COLD"
10 - 40 F.
UPPER RUMEN TEMP.
MIDDLE RUMEN TEMP.
LOWER RUMEN TEMP.
RECTAL TEMP.
H - HAY
G - GRAIN
W - DRINK
- DOWN
AIR TEMPERATURE
TIME, HOURS

6a

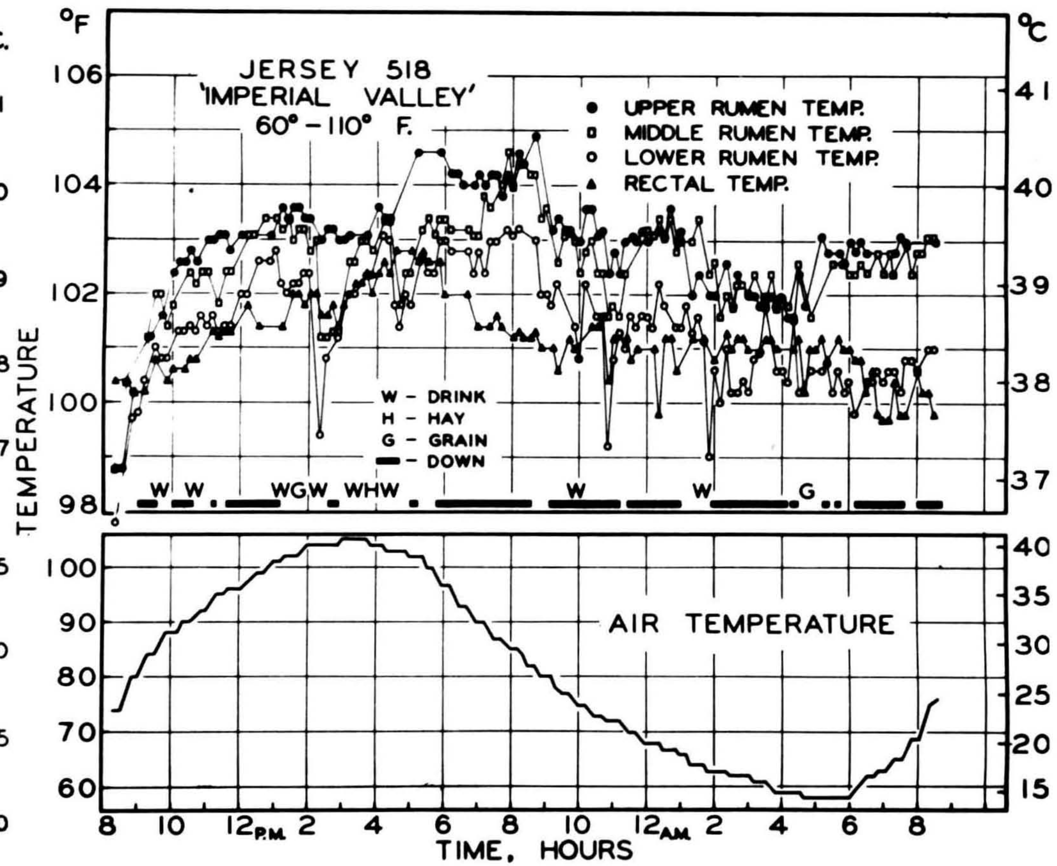


°F
°C.
JERSEY 518
'MIDWEST NORMAL'
40°- 70° F.
UPPER RUMEN TEMP.
MIDDLE RUMEN TEMP.
LOWER RUMEN TEMP.
RECTAL TEMP.
H-HAY
-DOWN
TEMPERATURE
AIR TEMPERATURE
TIME, HOURS

6b

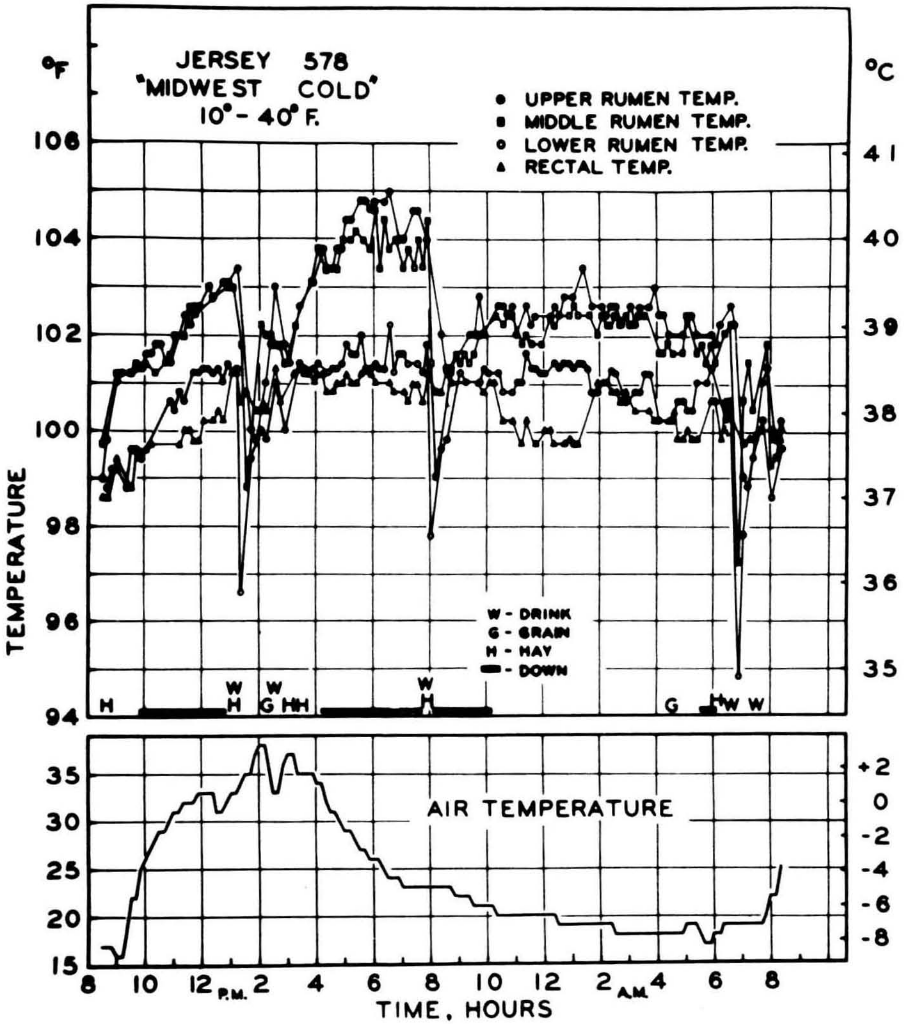


6c

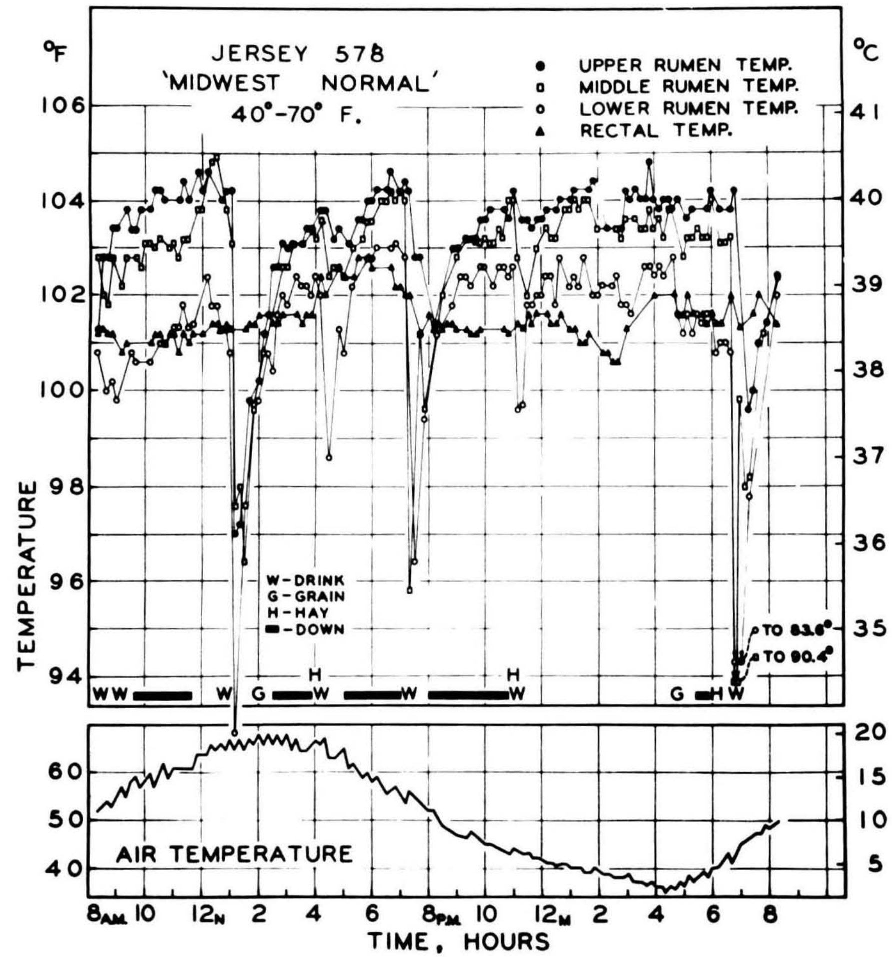


6d

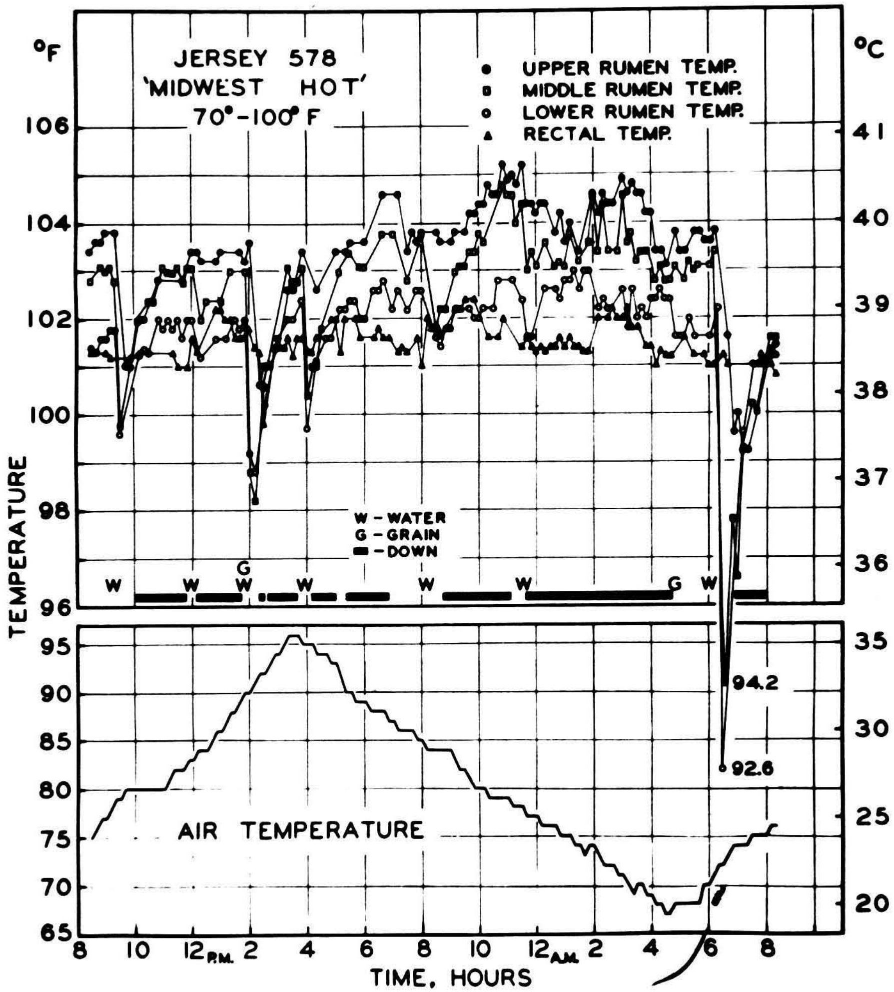
Figures 6a to d— The effect of four categories of climatic conditions (diurnal air temperatures) on Jersey cow 518. Note the decline in rumen temperature after watering (W), feeding grain (G), and feeding hay (H). See Tables 1 and 2 for the average numerical values and their variance, and Table 3a for Jersey cow 518.


JERSEY 578
"MIDWEST COLD"
10°-40° F.
UPPER RUMEN TEMP.
MIDDLE RUMEN TEMP.
LOWER RUMEN TEMP.
RECTAL TEMP.
°F
°C
TEMPERATURE
W - DRINK
G - GRAIN
H - HAY
- DOWN
AIR TEMPERATURE
TIME, HOURS

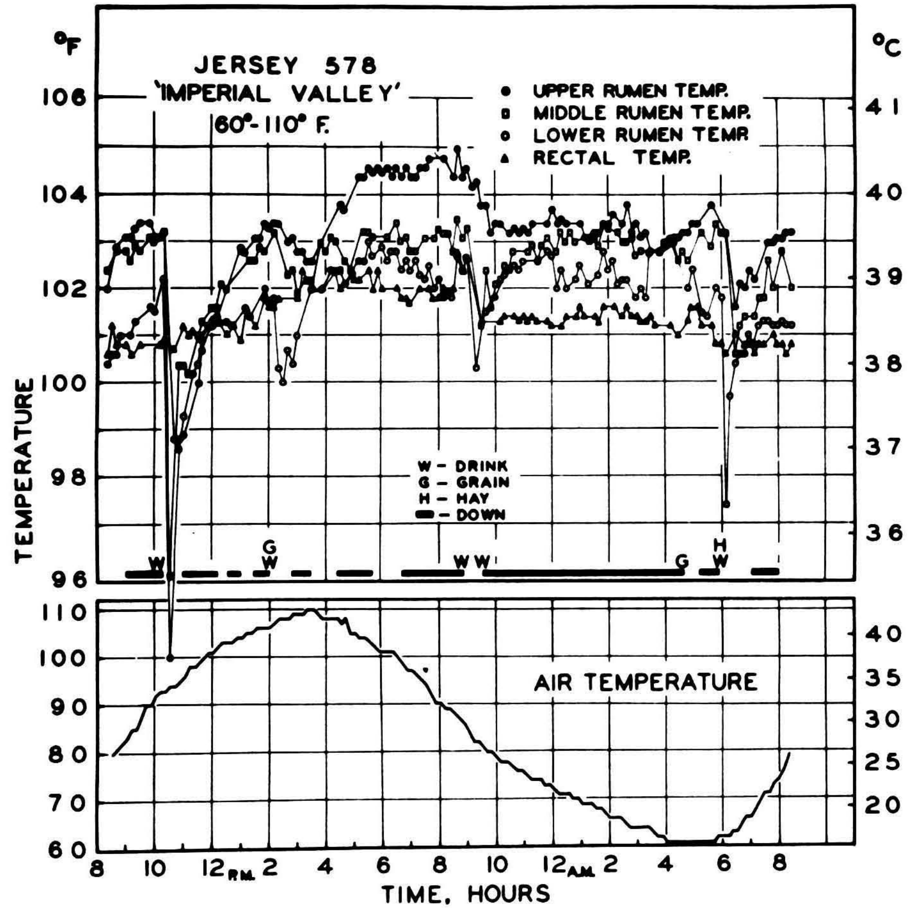
7a


JERSEY 578
'MIDWEST NORMAL'
40°-70° F.
UPPER RUMEN TEMP.
MIDDLE RUMEN TEMP.
LOWER RUMEN TEMP.
RECTAL TEMP.
°F
°C
TEMPERATURE
W-DRINK
G-GRAIN
H-HAY
-DOWN
TO 83.6°
TO 90.4°
AIR TEMPERATURE
TIME, HOURS

7b



7c



7d

Figures 7a to d—See legend for Figs. 6a to d for Jersey cow 578. See also Table 3b.

TABLE 1 -- MEAN DAILY RECTAL TEMPERATURES; ALSO MEAN TEMPERATURES OF LOWER, MIDDLE, AND UPPER RUMEN OBSERVED UNDER FOUR REGIONAL CLIMATIC CONDITIONS.

Climatic Conditions	Symbol	Temperature, °F Rectal	Lower Rumen	Middle Rumen	Upper Rumen
Midwest Cold	$\bar{X}$	100.0	100.6	101.9	102.2
(10^{o} - 40^{o}F)	s	0.647	1.094	1.111	1.066
	$s_{\bar{x}}$	0.024	0.047	0.041	0.040
Midwest Normal	$\bar{X}$	101.6	101.1	102.1	103.1
(40^{o} - 70^{o}F)	s	0.780	1.658	1.501	0.997
	$s_{\bar{x}}$	0.030	0.062	0.058	0.037
Midwest Hot	$\bar{X}$	101.3	101.8	102.7	103.2
(70^{o} - 100^{o}F)	s	0.424	1.265	1.282	0.666
	$s_{\bar{x}}$	0.017	0.047	0.048	0.025
Imperial Valley	$\bar{X}$	101.4	101.6	102.6	103.0
(60^{o} - 110^{o}F)	s	0.607	1.148	0.867	1.086
	$s_{\bar{x}}$	0.023	0.046	0.032	0.040

$\bar{X}$ = mean daily temperature = $\frac{\Sigma X}{N}$

s = standard deviation = $\sqrt{\frac{\Sigma(X^2) - \frac{(\Sigma X)^2}{N}}{N - 1}}$. The mean, plus and minus one standard deviation should include 68% of the observations, assuming a near normal dis-distribution.

$s_{\bar{x}}$ = Standard error of the mean = $\frac{s}{\sqrt{N}}$ = measure of the closeness of the computed mean to the true mean. In 68 times out of 100, the true mean lies between the computed mean and plus or minus $\frac{s}{\sqrt{N}}$, assuming a near normal distribution.

The values above were computed from the pooled values in each climatic region from both cows, Jerseys 518 and 578. See the charts for the hour-to-hour diurnal variations of the rectal and rumen temperatures in each cow in relation to the environmental air temperature and the effects of feeding and drinking on the temperatures.

TABLE 2 -- TWO CRITERIA OF ANALYSIS OF VARIANCE IN RECTAL TEMPERATURES WITH CHANGES IN FOUR CLIMATIC CONDITIONS

Identification	Jersey 518 Four Climatic Conditions	Jersey 518 Three Climatic Conditions	Jersey 578 Four Climatic Conditions	Jersey 578 Three Climatic Conditions
"F" Among Climatic Conditions	724.42	273.23	621.10	4.38
"F" Among Times of Day	9.29	23.82	3.84	2.14

The "F test", as applied to analysis of variance, is a test of significance whether the "within sample" variance is significantly larger than the "between sample" variance. The two variables in the present study are: "climatic condition" and "time of day". The variance of a set of data is expressed by $V = s^2 = \frac{\Sigma(X-\overline{X})^2}{N}$ in which s is standard deviation; X = individual item; $\overline{X}$, the mean of the items; N = number of items. To eliminate differences due to sample size, the above equation is written $V = s^2 = \frac{\Sigma(X-\overline{X})^2}{N - 1}$ in which N - 1 represents "degrees of freedom".

Numerically, the "F test", or "F ratio", is the ratio of variance between samples and variance within samples. The variance is computed with the aid of the above formula (values given in Table 1).

The significance of this test in the above table is that such extremely large "F" values among climatic conditions could not have occurred by chance even 1% of the time. Hence, the tentative conclusions that since chance variation is small, most of the variation, in the latter "F" values, is "caused by" (associated with) variation in diurnal environmental temperature, and to a lesser extent to other effects such as drinking and feeding. Excluding values suspected to be due to drinking and feeding from computation would introduce a bias that would nullify the statistical approach.

The two columns headed "Four Climatic Conditions" are based on a two criteria (Time of Day and Climatic Condition) analysis of variance, including all four climatic conditions. The columns headed "Three Climatic Conditions" omitted the "Midwest Cold" condition.

TABLE 3a -- INDIVIDUAL VALUES FOR JERSEY 518

Climatic Conditions	Symbol	Temperature, °F Rectal	Lower Rumen	Middle Rumen	Upper Rumen
Midwest Cold (10^{o} - 40^{o}F)	$\bar{X}$	99.9	100.8	101.8	102.0
	s	0.606	0.932	0.952	0.781
	$s_{\bar{x}}$	0.032	0.049	0.050	0.041
	Range	98.4-101.3	95.2-102.0	98.2-103.0	99.6-103.2
Midwest Normal (40^{o} - 70^{o}F)	$\bar{X}$	100.9	101.3	101.6	103.0
	s	0.870	1.068	1.062	0.678
	$s_{\bar{x}}$	0.046	0.056	0.056	0.360
	Range	96.4-102.8	99.6-102.6	100.2-103.6	100.8-104.0
Midwest Hot (70^{o} - 100^{o}F)	$\bar{X}$	101.1	101.7	102.9	102.9
	s	0.273	1.109	0.940	0.464
	$s_{\bar{x}}$	0.015	0.059	0.049	0.025
	Range	100.2-101.6	99.4-103.8	99.8-104.8	101.6-103.8
Imperial Valley (60^{o} - 110^{o}F)	$\bar{X}$	101.2	101.4	102.6	102.9
	s	0.685	1.078	0.882	1.007
	$s_{\bar{x}}$	0.037	0.056	0.046	0.053
	Range	99.7-102.8	97.4-103.4	98.2-104.6	98.6-104.9

See the footnotes for Table 1 for the definitions of the symbols $\bar{X}$, s, and $s_{\bar{x}}$. The range is the low and high observed values.

TABLE 3b.-- INDIVIDUAL VALUES FOR JERSY 578

Climatic Conditions	Symbol	Temperature, °F Rectal	Lower Rumen	Middle Rumen	Upper Rumen
Midwest Cold (10^{o} - 40^{o}F)	$\bar{X}$	100.1	100.5	102.1	102.3
	s	0.614	1.225	1.236	1.260
	$s_{\bar{x}}$	0.033	0.064	0.065	0.067
	Range	98.4-101.3	94.8-102.2	98.8-105.0	98.2-105.0
Midwest Normal (40^{o} - 70^{o}F)	$\bar{X}$	101.5	101.1	102.5	103.3
	s	0.473	1.105	1.060	1.073
	$s_{\bar{x}}$	0.026	0.058	0.056	0.056
	Range	100.4-102.8	83.6-103.1	90.4-104.9	96.4-104.8
Midwest Hot (70^{o} - 100^{o}F)	$\bar{X}$	101.5	101.7	102.5	103.3
	s	0.381	1.227	1.433	0.786
	$s_{\bar{x}}$	0.021	0.065	0.075	0.041
	Range	100.8-102.4	92.6-103.4	94.4-104.9	98.6-105.2
Imperial Valley (60^{o} - 110^{o}F)	$\bar{X}$	101.4	101.7	102.6	103.2
	s	0.494	1.205	0.852	1.149
	$s_{\bar{x}}$	0.026	0.063	0.048	0.064
	Range	100.6-102.4	94.2-103.0	95.9-103.6	98.8-105.4

See the footnotes for Table 1 for the definitions of the symbols $\bar{X}$, s, and $s_{\bar{x}}$. The ra
is the low and high observed values.

SUMMARY

Data are presented on rectal, rumen, and blood temperatures in two Jersey cows under various conditions with the following average results (details are given in tables and charts):

Average Rectal Temperature Under Four Climatic Conditions
"Midwest Cold" (10° to 40° F. diurnal rhythm), 100° F.; "Midwest Normal" (40° to 70° F.), 101.6° F; "Midwest Hot" (70° to 100° F.), 101.3° F; "Imperial Valley" (60° to 110° F.), 101.4° F.

Average Rumen Temperatures Under Four Climatic Conditions
"Midwest Cold": 100.6° F. lower rumen; 101.9° F. middle rumen; 102.2° F upper rumen. "Midwest Normal": 101.1° F. lower rumen; 102.1° F. middle rumen; 103.1° F. upper rumen. "Midwest Hot": 101.8° F. lower rumen; 102.7° F. middle rumen; 103.2° F. upper rumen. "Imperial Valley": 101.6° F. lower rumen; 102.6° F. middle rumen; 103.0° F. upper rumen.

The average rectal and rumen temperatures are thus about 1° F. higher at ambient temperatures 70° to 100°, or 60° to 110° F, than at 10° to 40° F diurnal rhythms. The upper rumen temperature (6 inches from the top) was about 2° F. higher than the lower rumen (about 18 inches from the top) or than the rectal temperature. The middle rumen (12 inches from the top) was about midway in temperature between top and bottom rumen temperatures and was about 1° F. above the lower rumen and rectal temperatures.

At constant environmental temperature 60° to 65° F., the upper rumen temperature was about 3° F. above the lower rumen and almost 4° F. above the rectal temperatures. Administration of 14 pounds of 65° F. water, at a constant environmental temperature of about 65° F., sharply reduced the rumen temperature and about an hour was required to get the rumen temperature to normal. Fasting 24 hours reduced the rumen temperature about 3° F. Feeding 4 pounds of hay to a fasting cow increased the rumen temperature about 3° F. within 25 minutes after the hay was consumed. The rectal temperatures were but slightly affected by these operations.

The right jugular blood temperature was constant at about 99° F. down to 17 inches; then remained at 100.3° F. on moving the thermocouple down to 36 inches from the top.

Rectal, rumen, and environmental temperatures tended to vary together in diurnal rhythms. There is no doubt of the presence of inherent or endogenous diurnal rectal temperature rhythm. This endogenous diurnal rectal temperature rhythm was, however, complicated by changes in the rhythm of the environmental temperatures and feeding. Analysis of variance (Table 2) indicates that the diurnal environmental temperature rhythm contributed substantially to the rectal temperature rhythm.

Antipyrine administration at an ambient temperature of about 63° F was followed first by decline in rectal and rumen temperatures, then by

shivering and rise in temperatures. The time sequence was: first, rise in rectal temperature, followed by rise in rumen temperature. In the preceding feeding experiments, the temperature-change sequence was in the reverse: first, rise in rumen temperature after feeding, followed by rise in rectal temperature. These differences in sequence suggest that heat is produced anaerobically in the rumen, independently of the overall oxidation in the body proper, and that this anaerobic rumen heat production can be measured (after fast and re-feeding) by the difference between total heat elimination by direct colorimetry, and oxidative heat production by indirect (oxygen-consumption) calorimetry.

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