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Environmental Physiology

With Special Reference to Domestic Animals

XIII. Influence of Increasing Temperature, 40° to 105° F, on Heat Production and Cardiorespiratory Activities in Brown Swiss and Brahman Cows and Heifers

H. H. KIBLER AND SAMUEL BRODY

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COLUMBIA, MISSOURI

TABLE 1.--TEMPERATURE CALENDAR AND TEST SCHEDULE*

Chamber Temperature Level, °F		Relative Humidity %		Date 1950				Number of Tests			
				Heifers		Cows		Cardio-respiratory		Heat Production	
Heifers	Cows	Heifers	Cows	From 3 PM	To 3 PM	From 3 PM	To 3 PM	Heifers	Cows	Heifers	Cows
40	40	64	61	Feb. 6	Mar. 3	Feb. 6	Mar. 3	18	18	3	3
50	50	65	58	Mar. 3	Mar. 17	Mar. 3	Mar. 17	10	10	2	2
60	60	76	70	Mar. 17	Mar. 31	Mar. 17	Mar. 31	10	10	2	2
70	70	72	70	Mar. 31	Apr. 14	Mar. 31	Apr. 14	9	9	2	2
80	80	69	67	Apr. 14	Apr. 28	Apr. 14	Apr. 28	10	10	2	2
85	85	69	68	Apr. 28	May 5	Apr. 28	May 5	5	5	1	2
90	90	62	66	May 5	May 12	May 5	May 12	6	4	1	2
89	95	64	59	May 12	May 19	May 12	May 15	5	1	1	1
	100		56			May 15	May 17		2		1
	105		56			May 17	May 18		1		1
	to 80**		53			May 18	May 19		1		
95	72	48	72	May 19	May 22	May 19	May 25	2	4	1	1
100		56		May 22	May 24			2		1	
105		51		May 24	May 25			1		1	
to 60#	to 50##	65	58	May 25	May 26	May 25	May 26	1	1		
40	40	66	63	May 26	Jun. 2	May 26	Jun. 2	5	5	1	1
40	40	66	63	Jun. 2	Jun. 9	Jun. 2	Jun. 9	2	3	1	1

* All tests were made between 1 PM and 3 PM.

** Average temperature for the 24-hour period was 90°F.

\# Average temperature for the 24-hour period was 75°F.

\## Average temperature for the 24-hour period was 57°F.

ACKNOWLEDGMENT

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Environmental Physiology

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XIII. Influence of Increasing Temperature, 40° to 105° F, on Heat Production and Cardiorespiratory Activities in Brown Swiss and Brahman Cows and Heifers

H.H. Kibler and Samuel Brody

INTRODUCTION

This, the fourth, in a series of reports on the influence of wide range but gradual changes in environmental temperature on heat production, rectal temperature and cardiorespiratory activities in individual dairy cows of different breeds,[1, 2, 3,*] covers the period February to June 1950. During this period the temperature in the experimental chambers was increased from 40° to 105°F according to the schedule shown in Table 1.

This study provides data on the reactions of the above functions to rising temperature and, with due regard to the few experimental animals, offers the opportunity to form some estimates of: (1) the effect of evolutionary adaptation, as we included three European-evolved Brown Swiss cows and three Indian-evolved Brahman cows; (2) the effect of milk yield level and, therefore, feed consumption, as the Brown Swiss cows produced 40 to 50 lbs. milk and consumed about 26 lbs. TDN a day, in contrast to the Brahman cows which produced no milk and consumed about 10 lbs. TDN a day; (3) the effects of age and body size, as we also included three Brown Swiss heifers about 7 months of age and three Brahman heifers about 9 months of age.†

Since differences in feed consumption and milk production are associated with differences in heat production, it seems probable that cows which produce large amounts of heat by virtue of their high milk production and high feed consumption would be more seriously affected by rising temperatures than cows which produce no milk and consume little feed; likewise, that, other things being equal, large animals which have less surface area per unit weight available for heat dissipation would be more seriously affected by rising temperature than small cows with greater surface per unit weight; and finally that animals

*See page 13 for numbered references.

†See Ref. 4 for detailed descriptions of the animals, including detailed figures on body weight, feed and water consumption, and milk yield. The body weights at the beginning and end of the experiment are summarized in Table 2 of the present report.

TABLE 2.--INITIAL AND FINAL BODY WEIGHTS, LBS.*

Heifer	Initial	Final	Cow	Initial	Final
		Brown Swiss			
2	354	499	20	1272	1220
3	391	523	16	1341	1252
1	447	620	24	1422	1359
		Brahman			
2	426	554	209	966	1075
3	432	564	189	964	1038
1	532	661	190	1022	1120

* For body weights at the different temperature levels, see Tables 4 and 6, Ref. 4.

evolved in and therefore adapted to tropical regions would be better able to withstand rising temperature than animals evolved in cool regions. This experiment provides quantitative data for use in checking these assumptions and for gaining insight into the limiting mechanisms.

METHODS

The method of measuring heat production from oxygen consumption and carbon dioxide and methane production by the open-circuit method has been previously described and discussed.[1, 2, 3] As in the preceding experiments, respiration rates were obtained from flank movement counts; and pulse rates by manual palpation. Rectal temperatures were measured with a clinical thermometer and checked occasionally with a calibrated resistance thermometer.

The resistance thermometer, constructed by the senior author for this work, employed a thermistor (thermally sensitive resistor) as one arm of a conventional bridge circuit. The thermistor element was sealed in the end of a seven-inch plastic tube for deeper insertion than was possible with the ordinary four-inch clinical thermometer.

A comparison of results obtained by the two types of thermometers showed that on the average the more deeply inserted resistance thermometer read 0.2°F higher than the clinical thermometer. As this difference was inconsequential, we concluded that the ordinary clinical mercury thermometer gave satisfactory results.

DATA AND THEIR INTERPRETATION

Graphic comparisons of the responses of the individual cows and heifers to progressive increases in environmental temperature are presented in Figs. 1 to 4 in the text. The numerical data are given in Tables 3 to 7 in the Appendix. Fig. 5 integrates the present Brown Swiss and Brahman data with those accumulated on Jersey, Holstein, and Brahman cows during the past two years.

Heat Production Per Animal and Per Unit Surface Area: At chamber temperatures from 40° to about 70° or 80°F, the heat production of the normally fed, standing animals about 11 hours after the morning grain feeding* was, in terms of Cal./hr. (Fig. 1), about 900 for the lactating Brown Swiss cows; 500 for the dry Brahman cows; and 300 to 400 for the heifers. In terms of Cal./sq. m/day (Fig. 2), the corresponding values were approximately 4000 for

*Hay was kept in the mangers at all times.

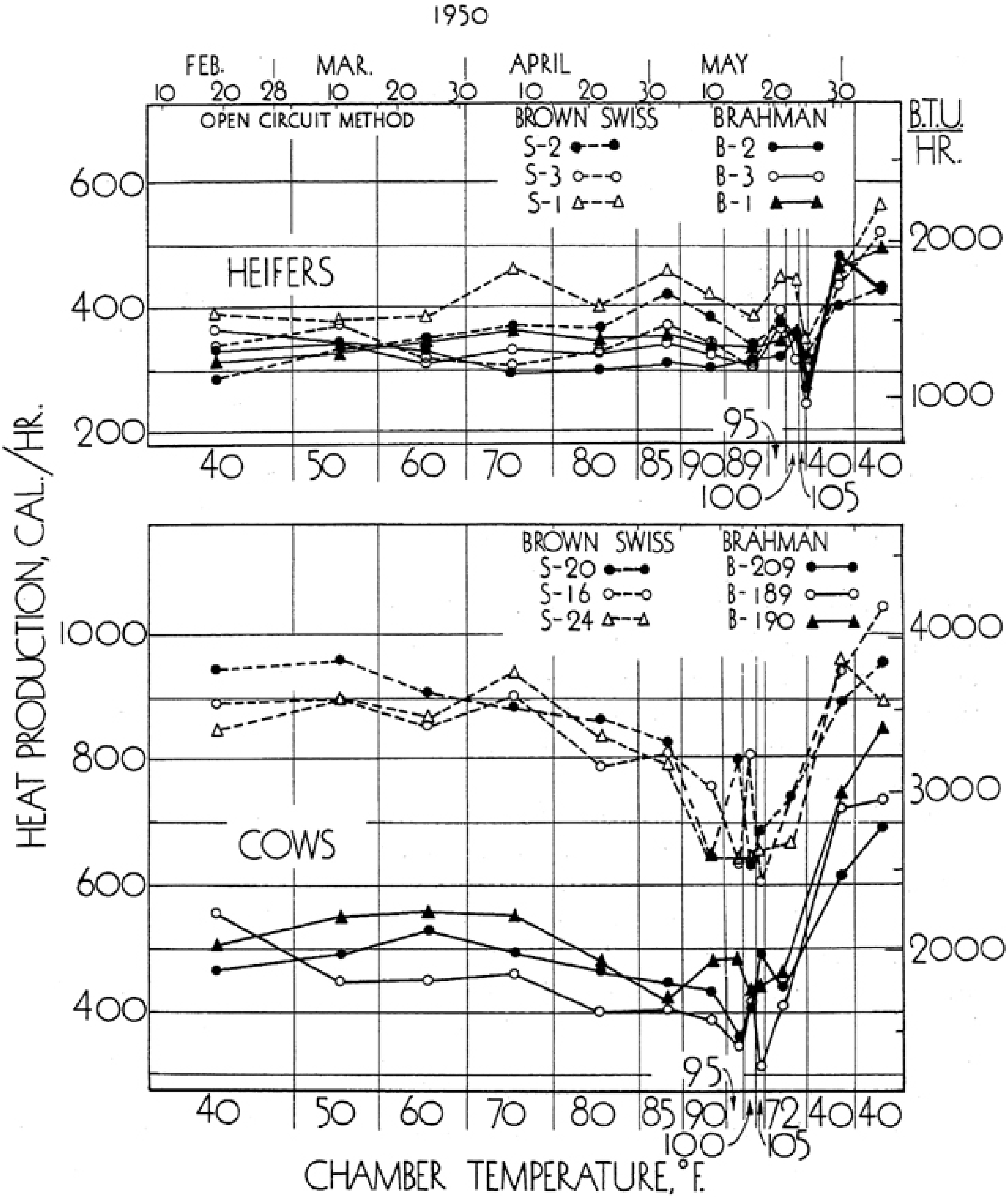

Fig. 1.—Comparison of the heat production of individual Brown Swiss and Brahman heifers (top) and lactating Brown Swiss and dry Brahman cows (bottom) in relation to gradually increasing environmental temperature.

the Brown Swiss cows; 2400 for the Brahman cows; 3000 for the Brown Swiss heifers; and 2300 for the Brahman heifers.

On increasing the environmental temperature from 85° to 105°F, the heat production decreased to about 650 Cal./hr., or by 25 per cent, in the Brown Swiss and to 425 Cal./hr., or by 15 per cent, in the Brahman cows. These are rough approximations since the data are variable in the 90° to 105°F range due apparently to the normal respiratory distress at the higher temperatures as shown in respiration rate curves (Fig. 4), especially when combined with the superimposed restraint of the mask used for the measurement. The 15 per cent decrease in heat production of the three dry Brahman cows was about the same as the value found the preceding year on two of these same animals when they were lactating. The temperature at which the decrease in heat production became noticeable was about 10°F higher in the Brown Swiss and Brahman cows than in Jersey and Holstein cows tested in similar earlier experiments.

The higher heat production per animal of the lactating Brown Swiss over the dry Brahman cows (Fig. 1) was due, of course, to their greater body weight, higher feed consumption and heavy milk production, with associated heat increments. The lactating Brown Swiss may, perhaps, also have an inherently higher basal metabolism than the dry Brahmans, but it is obviously difficult to test this idea experimentally. It does not seem possible to measure the basal metabolism of lactating—therefore feeding—animals. Even if feeding and milking cease as the result of high environmental temperatures (100° to 105°F) the stimulating effect of the neuroendocrine system associated with potential lactation and the maintenance of the large mammary system[6] may still be a substantial and significant factor. The 40 per cent higher heat production per unit surface area* (Fig. 2) of the Brown Swiss over the Brahman heifers (both non-milking) at 100° to 105°F, when the feed consumption was greater in the Brahmans is more significant support for the idea that the Brahmans have the lower basal metabolism. There is, however, an element of uncertainty in the estimated surface areas of the Brown Swiss and Brahman heifers. While, therefore, it appears that the basal metabolism is lower in these Indian-evolved than in these European-evolved cattle, there is no definite proof for it at this time.

In the heifers, the heat production per animal of the Brahmans appears nearly as high as that for the Brown Swiss (Fig. 1, upper section) but considering that the Brahmans were about 2½ months older and weighed on the average 17 per cent more than the Brown Swiss at the beginning of the experiment, it seems probable that on a weight basis, as well as on a surface area basis, the heat production of the Brahmans was lower than that of the Brown Swiss.

Heat Production in Relation to Growth Rate: Increasing temperature apparently upset the normal relationship between heat production and body weight in the heifers. Instead of increasing with the ⅔ or some higher power of body weight, heat producton remained constant in five of the six heifers during the increase of environmental temperature from 40° to 100°F, although gains in body weight during the 3½-month period ranged from 21 to 37 per cent. The heat production decreased sharply at 105°F in all heifers but rose to the highest levels during the experiment in the subsequent two-week period when the environmental temperature was reduced to 40°F.

*The surface area of the Brahman cows and heifers was estimated to be 12 per cent greater than that of Jerseys and Holsteins of the same body weight as discussed on page 14 of Ref. 3. The surface area of Brown Swiss cattle was not measured but was assumed to be the same as that of Jerseys and Holsteins of the same body weight.

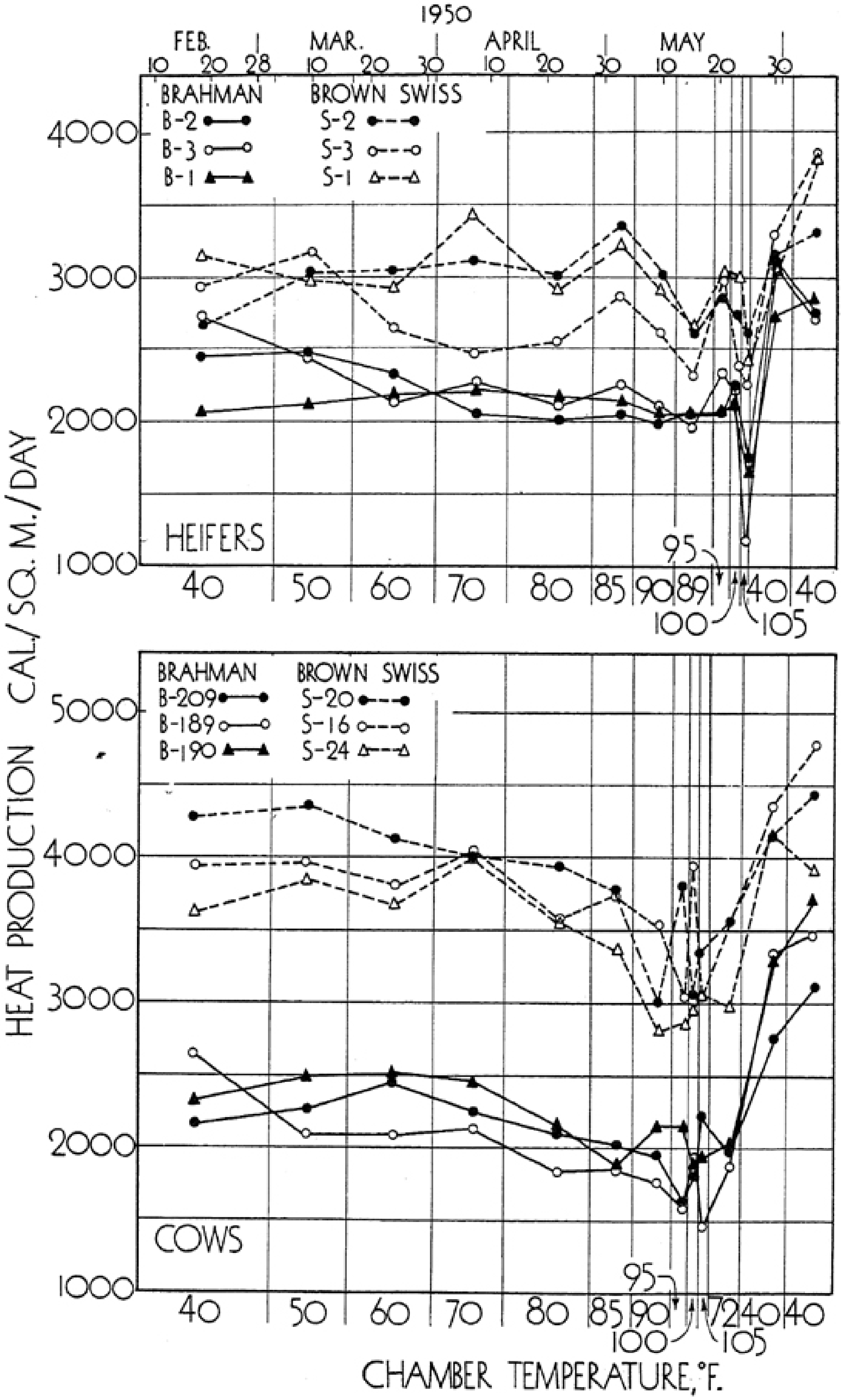

Fig. 2.—Heat production per square meter of surface area in individual Brown Swiss and Brahman heifers (top) and lactating Brown Swiss and dry Brahman cows (bottom) in relation to gradually increasing environmental temperature.

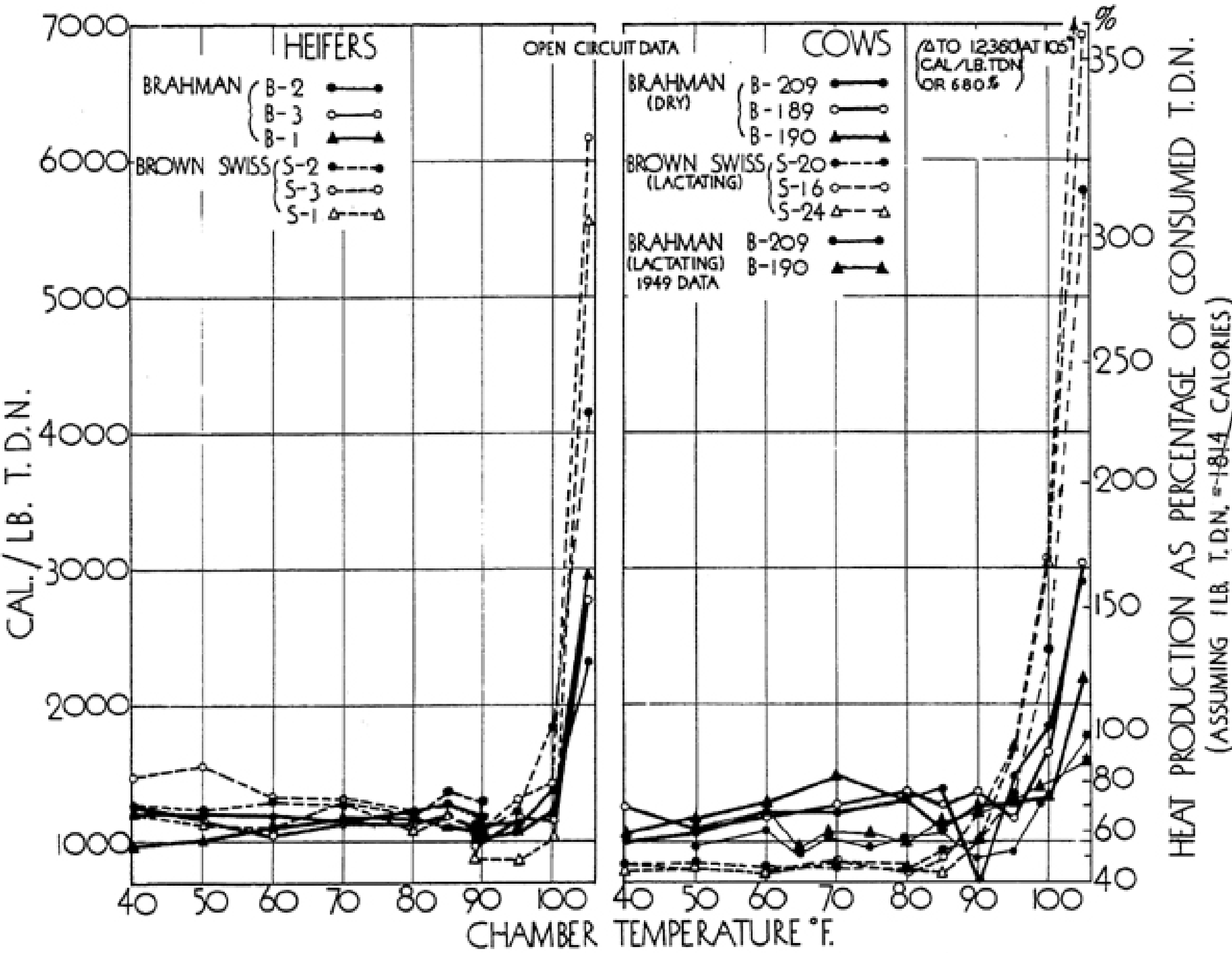

Fig. 3.—Ratio of heat production to total digestible nutrient consumption in Brahman and Brown Swiss heifers (left) and dry Brahman and lactating Brown Swiss cows (right) in relation to increasing temperature. The left-hand scale expressed in calories per pound TDN and the right-hand scale expressed in heat production calories as a percentage of consumed TDN calories (1 lb. TDN = 1814 calories) apply to both the heifer and cow data.

Heat Production in Relation to TDN Consumption: Fig. 3 (right section) shows that the heat production per pound of TDN consumed stayed approximately constant in all cows (though at different levels) between 40° and 85°F but rose rapidly in the Brown Swiss above 85°F and in the Brahmans above 95°F.

The percentage scale of ordinates on the right side of Fig. 3 shows the relation of heat production Calories to consumed TDN Calories (assuming that the heat equivalent of TDN is 1814 Cal./lb.*). On this assumption, the heat production Calories between 40° and 85°F chamber temperature was equivalent to about 45 per cent of the TDN Calories of the feed in the high milking Brown Swiss cows, 55 per cent in low milking Brahman cows (1949 data) and 65 per cent in the dry Brahman cows (1950 data). Values in excess of 100 per cent were reached at about 95°F in the Brown Swiss and between 95° and 105°F in the Brahmans, indicating that at these high temperatures feed consumption had declined below maintenance levels and that body stores were being used as fuel.

*Page 32 of Ref. 5.

In the growing heifers (Fig. 3, left section), the heat production energy was constant at about 60 per cent of the TDN consumption energy level at temperatures from 40° to 100°F in both the Brown Swiss and Brahmans. At 105°F the rise in this ratio was much more rapid in the Brown Swiss than in the Brahman heifers, indicating a greater depletion of body stores, or feed deficit in the Brown Swiss than the Brahman heifers. The Brahman heifers were on the average two and one-half months older than the Brown Swiss heifers, and this difference in age and weight may have been a factor in this apparent difference in heat tolerance as measured by the decline in feed consumption in relation to heat production.

Pulse Rate: In preceding bulletins[2, 3] we have discussed the implications of the general parallelism (or under special conditions, the non-parallelism) of the pulse rate and heat production levels with changing environmental temperature. The data on the cows (Fig. 4, upper right) followed the usual pattern, the pulse rate like heat production decreased with rising chamber temperature. When the body temperature reached abnormally high levels (106° to 108°F), however, the pulse rate increased. When the chamber temperature was again lowered to 40°F, the pulse rate like the heat production was low at first but gradually increased to normal levels.

The pulse rate curves for the heifers (Fig. 4, upper left) differed in two respects from those for the cows. The pulse rate decreased in all heifers as the chamber temperature was increased from 40° to 100°F, although the heat production was approximately constant. Also the pulse rate did not rise at high body temperature. The decline in pulse rate may be attributed, in part, to the normal decrease in pulse frequency with increasing age and body weight in growing animals. In growing mules[7], for example, we found that the pulse rate decreased with the –0.42 power of body weight.

Respiration Rate: The Brown Swiss heifers had higher respiration rates than the Brahman heifers at all temperatures (Fig. 4, lower left), and although the curves for both breeds began to rise steeply at 70°F chamber temperature, the rise was more rapid in the Brown Swiss than the Brahmans. Respiration rates per minute as high as 160 were reached by the Brown Swiss heifers at 100° to 105°F, and as high as 130 by the Brahman heifers at 105°F.

The respiration rate curves for the cows (Fig. 4, lower right) followed much the same pattern as the curves for the heifers, but maximum rates were not quite so high. The rise in the curves for the lactating Brown Swiss cows occurred at a lower temperature and was more rapid than the rise in the curves for the dry Brahman cows.

Rectal Temperature: The response of rectal temperature to rising environmental temperature was very similar in both the Brown Swiss and Brahman heifers (Fig. 4). Below 90°F the rectal temperature was constant except in Brown Swiss S-20 in which higher values occurred above 80°F. Above 95°F, the rise in rectal temperature was quite steep, reaching average values of 106.7°F in the Brown Swiss and 105.8°F in the Brahmans at 105°F room tem-

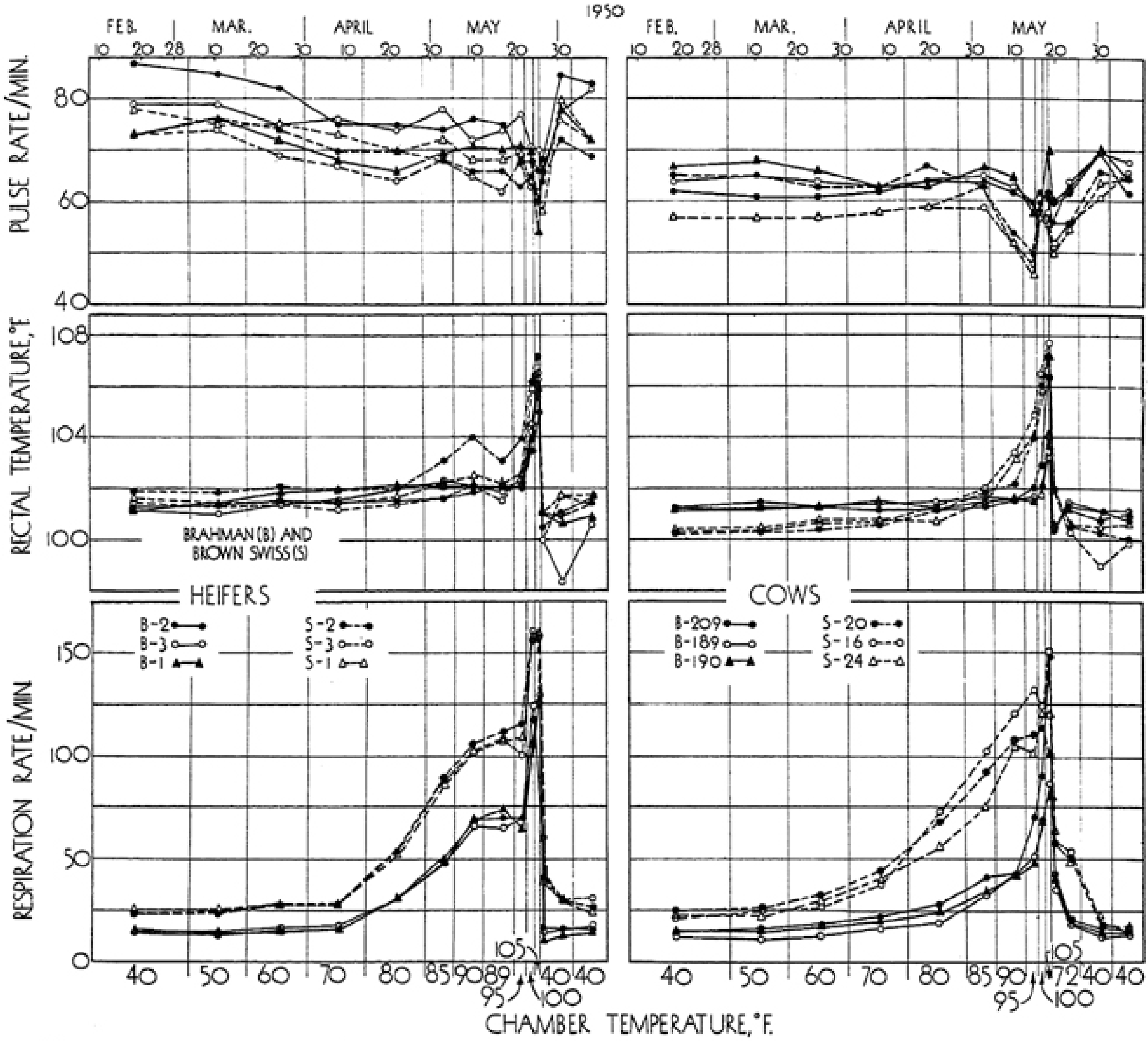

Fig. 4.—Pulse rate, rectal temperature, and respiration rate in Brown Swiss and Brahman heifers (left) and in lactating Brown Swiss and dry Brahman cows (right) in relation to gradually increasing environmental temperature.

perature. A rapid fall in rectal temperature to values below the initial levels at 40°F occurred when the room temperature was reduced from 105° to 40°F, but was followed by a gradual return toward normal levels.

In the cows, the rise in rectal temperature began at about 80°F room temperature in the Brown Swiss and at about 100°F in the Brahmans. Average values of rectal temperature of 107.6°F in the Brown Swiss, and 104.7°F in the Brahmans were reached at 105°F room temperature.

Reactions at Different Temperatures in Relation to Reactions at 50°F: Fig. 5 compares the present data on lactating Brown Swiss and dry Brahman cows with data from preceding bulletins[1, 2, 3] on lactating Jersey, Holstein, and Brahman, and dry Holstein cows. The reactions at each environmental temperature level were computed as percentages of the reactions at the 50°F level.

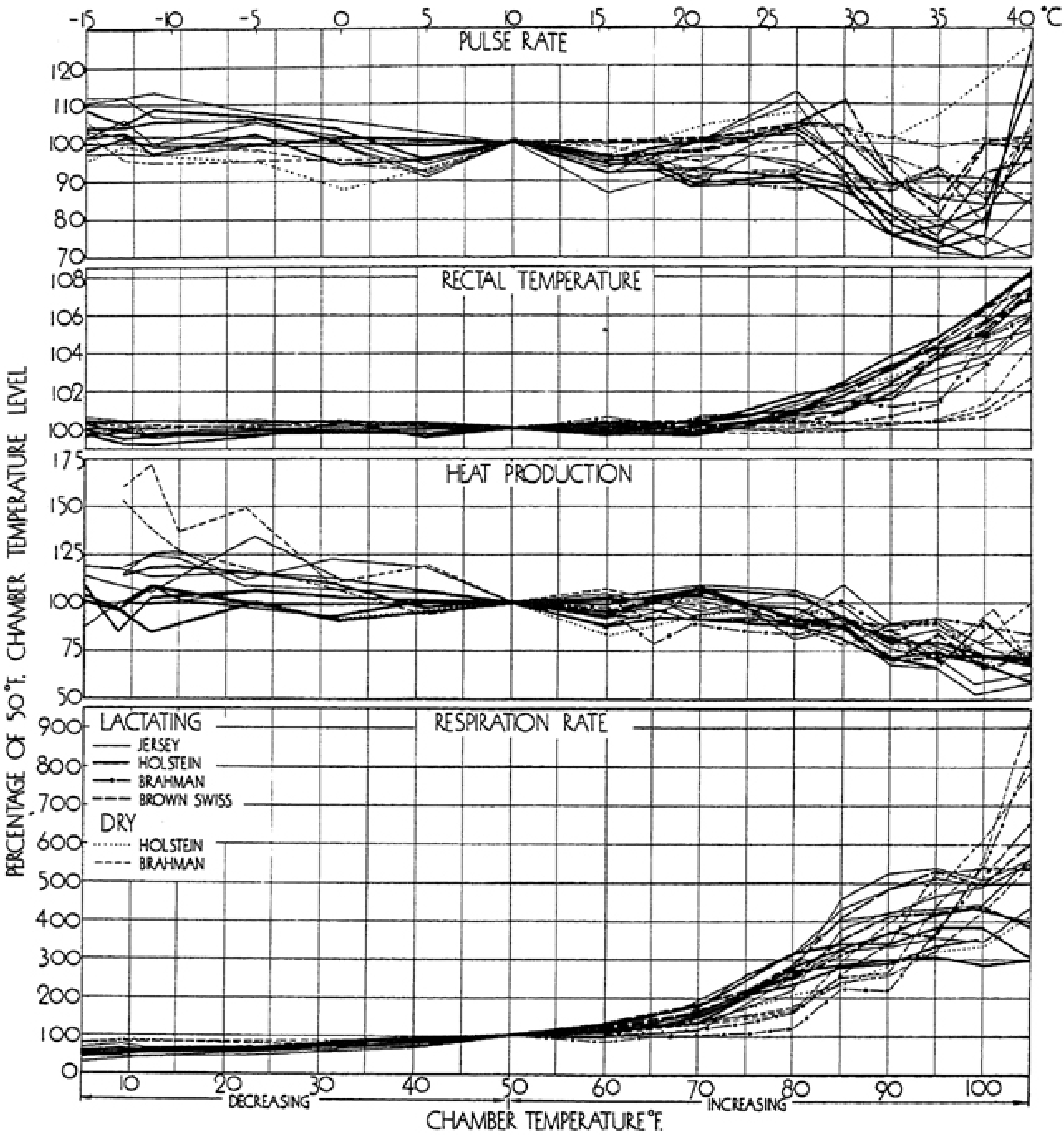

Fig. 5.—Summary of present and previously reported heat production and cardiorespiratory data on individual Jersey, Holstein, Brahman, and Brown Swiss cows for environmental temperatures 5° to 105°F, expresses as percentages of the respective levels at 50°F environmental temperature.

This method of analysis has the disadvantage of placing undue dependence on the data at the 50°F level, taken usually near the beginning of the experiment, but has the great advantage of equalizing the data for cows of different body weight. This compilation of data still has too few cows of each breed and too few lactating and dry cows within a breed to draw general conclusions but is of sufficient scope to broaden some of our earlier tentative conclusions.

The curves (Fig. 5) seem to indicate that tolerance to heat is associated with large surface area per unit weight, as in relatively small cows (Jerseys), or as in cows with increased surface in appendages (Brahmans). Ability to withstand high temperatures is likewise associated with reduction in feed consumption, milk production and therefore heat production; but this adaptive reaction is, perhaps, not strictly an indication of true heat tolerance. The above associations are indicated by the steady rise in rectal temperature in the large Holsteins and high-milking Brown Swiss in comparison to the delayed and lesser rise in rectal temperature in the dry and low-milking Brahmans. Tolerance to cold, it appears, is associated with small heat-dissipating surface in relation to body weight as in large cows (Holsteins) and with high milk production, high feed consumption and associated heat increment of feeding. Note the rise (wasteful from the animal husbandman's viewpoint) in heat production with decreasing temperature in the non-lactating (over-surfaced for low temperature) Brahmans. It is particular noteworthy that lowering the temperature from 105°F and holding it at 40°F over a three-week period increased the heat production above the initial 40° level by about 5 per cent in the Brown Swiss and by 40 per cent in the Brahman cows (Fig. 1). It seems probable that the greater rise in heat production in the Brahman than in the Brown Swiss cows resulted from their relatively greater body surface. Over a longer 40°F exposure period, increased hair growth in the Brahmans might be expected to compensate for their larger surface and allow them to maintain their normal body temperature at a lower level of heat production.

SUMMARY AND ABSTRACT

Data are presented on heat production (by the open-circuit respiratory exchange method), rectal temperature, pulse and respiration rates with rising environmental temperature, 40° to 105°F, at 5° to 10°F intervals, for three high-milking (40 to 50 lbs. milk a day), 1200 to 1400 lb. Missouri-bred Brown Swiss cows; three dry 1000 lb., Texas-bred Brahman (Indian) cows; three each of Brown Swiss and Brahman, 400 to 600 lb. heifers.

The effects of rising temperature on the various physiological reactions became critical (significantly changed from the normal levels at thermoneutrality) at the following approximate environmental temperatures for rectal temperature, pulse rate and heat production: 85°F in the Brown Swiss cows, 100°F in the Brahman cows, 95° to 105°F in the Brown Swiss and Brahman heifers; for respiration rate, 70°F in the Brown Swiss cows, 85° in the Brahman cows, 80°F in the Brown Swiss and Brahman heifers. At 105°F environmental temperature the average rectal temperatures were 107.6°F in the Brown Swiss cows, 104.7°F in the Brahman cows, 106.7°F in the Brown Swiss heifers, and 105.8°F in the Brahman heifers. The appetite, or feed consumption, in the Brahmans was greater at 100° to 105°F than in the Brown Swiss, although their heat production was less.

While the differences between the reactions of the Brahman (Indian) and Brown Swiss (European) heifers were small, the differences between the two categories of cows were considerable. Were these differences between the cows due in part or in whole to the fact that the Brahman cows were dry and the

Brown Swiss cows were heavily lactating and therefore heavily feeding? We shall not have a definite answer to the question of relative heat tolerance of European and Indian cows until we shall obtain either similar data on non-milking European cows or on heavily milking Indian cows.

Our rather limited observations, however, seem to indicate that the Brahman heifers are more heat tolerant than the Brown Swiss; since at 105°F they consumed more feed than the Brown Swiss heifers, yet had a lower rectal temperature and heat production.

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APPENDIX

TABLE 3.--AVERAGE* HEAT PRODUCTION PER ANIMAL FOR SUCCESSIVE TEMPERATURE LEVELS AS OBTAINED BY THE OPEN-CIRCUIT METHOD

Temperature Level, °F		HEIFERS						COWS					
		Brown Swiss			Brahman			Brown Swiss			Brahman		
Heifers	Cows	2	3	1	2	3	1	20	16	24	209	189	190
						Cal/hr.							
40	40	286	336	388	328	366	314	944	892	848	464	556	506
50	50	333	372	378	339	342	327	960	897	897	498	447	549
60	60	348	315	384	327	309	345	909	855	864	528	450	558
70	70	369	303	459	291	333	363	885	903	939	492	459	552
80	80	366	321	402	294	324	348	867	792	837	462	399	480
85	85	420	366	456	306	342	354	831	813	792	444	405	423
90	90	384	336	420	300	324	336	648	759	645	432	387	483
89	95	336	306	384	312	306	330	804	636	642	360	348	486
	100							630	810	648	408	414	432
	105							684	606	654	492	312	438
95	72	372	390	444	318	366	348	744	750	666	438	408	462
100		354	312	438	348	348	360						
105		324	288	348	270	246	276						
40	40	402	432	450	480	480	462	894	942	960	618	726	750
40	40	432	516	564	426	426	492	954	1044	894	696	762	852

* See Table 1 for the number of observations in each average.

TABLE 4.--AVERAGE* PULSE RATE, RESPIRATION RATE, AND RECTAL TEMPERATURE FOR SUCCESSIVE TEMPERATURE LEVELS

Temperature Level, °F		HEIFERS						COWS					
		Brown Swiss			Brahman			Brown Swiss			Brahman		
Heifers	Cows	2	3	1	2	3	1	20	16	24	209	189	190
		Pulse Rate Per Minute #											
40	40	73	73	78	87	79	73	65	57	57	62	64	67
50	50	76	74	75	85	79	76	65	57	57	61	65	68
60	60	74	69	75	82	75	72	63	57	57	61	64	66
70	70	70	67	73	75	76	68	63	58	58	62	63	63
80	80	70	64	70	75	74	66	67	59	59	64	64	63
85	85.	68	68	72	74	78	69	63	59	63	64	65	67
90	90	66	65	68	76	72	71	54	52	52	62	63	65
89	95	66	62	68	75	74	70	50	48	46	60	60	58
	100							60	57	57	62	57	59
	105							62	58	56	61	57	70
	90							56	52	50	60	56	60
95	72	63	68	69	68	77	71	56	56	55	62	64	63
100		65	63	64	68	71	70						
105		60	62	60	66	70	54						
75	57	64	64	58	68	66	66	60	54	56	77	60	73
40	40	72	76	80	85	76	78	66	61	64	70	70	70
40	40	69	72	72	83	82	72	65	66	65	62	68	65
		Respiration Rate Per Minute **											
40	40	24	24	25	14	14	16	24	21	23	14	12	15
50	50	24	24	25	13	14	14	26	25	22	16	11	15
60	60	28	28	28	15	16	15	32	26	30	18	12	17
70	70	29	28	28	16	17	16	44	37	40	22	16	20
80	80	54	54	53	31	30	31	68	73	56	28	19	24
85	85	89	89	86	48	48	49	92	102	75	41	32	34
90	90	106	102	102	69	66	69	108	120	104	43	43	41
89	95	112	108	107	70	65	74	110	132	102	70	52	48
	100							113	124	120	90	68	67
	105							100	150	120	148	86	80
	90							58	60	64	43	35	40
95	72	116	100	109	70	70	64	50	54	49	21	18	20
100		156	160	157	117	124	105						
105		158	158	160		130	132						
75	57	42	40	40	15	14	10	25	28	30	17	14	16
40	40	30	30	30	16	15	13	18	19	23	16	12	14
40	40	27	31	24	16	17	14	17	16	16	15	14	14
		Rectal Temperature, °F##											
40	40	101.9	101.5	101.6	101.3	101.2	101.2	100.3	100.4	100.5	101.3	101.2	101.2
50	50	101.8	101.3	101.5	101.4	101.0	101.4	100.4	100.4	100.6	101.5	101.3	101.3
60	60	102.0	101.4	101.5	101.6	101.5	101.8	100.5	100.8	100.8	101.3	101.3	101.3
70	70	101.9	101.2	101.4	101.5	101.6	101.9	100.7	100.8	100.8	101.2	101.4	101.4
80	80	102.0	101.4	101.6	101.5	102.0	102.1	101.1	101.3	100.8	101.2	101.5	101.2
85	85	103.1	101.7	102.2	101.6	102.3	102.1	101.9	102.0	101.5	101.3	101.7	101.6
90	90	104.0	102.1	102.6	101.8	102.1	102.1	102.2	103.8	103.2	101.6	101.6	101.7
89	95	103.1	101.6	102.1	102.1	101.8	102.0	104.0	104.9	104.2	102.0	101.7	101.6
	100							106.0	106.6	105.8	102.9	101.9	102.3
	105							107.3	107.7	107.7	106.4	103.5	104.1
	90							102.0	103.2	102.0	100.4	100.4	100.6
95	72	103.9	102.6	102.6	102.0	102.2	102.4	100.7	100.4	100.8	101.3	101.4	101.0
100		106.1	104.2	105.9	103.6	104.6	103.9						
105		107.2	106.6	106.4	105.0	106.3	106.0						
75	57	101.0	100.2	101.0	100.5	100.0	100.5	100.6	100.4	100.7	101.5	101.6	101.1
40	40	100.9	101.8	101.8	101.0	97.6	100.7	100.4	99.0	100.6	101.2	101.2	100.8
40	40	101.4	101.4	101.6	101.6	100.7	100.9	100.2	99.9	100.7	100.8	101.2	101.1

* See Table 1 for the number of observations in each average.
\# Manual counts.
** From flank movement counts.
\#\# Measured with clinical thermometer.

TABLE 5.--AVERAGE* OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION, AND METHANE PRODUCTION PER ANIMAL FOR CONSECUTIVE TEMPERATURE LEVELS

Temperature Level, °F		HEIFERS						COWS					
		Brown Swiss			Brahman			Brown Swiss			Brahman		
Heifers	Cows	2	3	1	2	3	1	20	16	24	209	189	190
		Oxygen Consumption, Liters Per Hour											
40	40	58	68	80	67	74	64	187	177	170	94	113	100
50	50	67	76	76	67	68	65	191	178	178	97	89	109
60	60	71	64	77	65	62	70	180	169	172	106	91	110
70	70	74	62	94	58	67	73	177	180	190	100	94	111
80	80	74	65	81	59	64	70	172	160	167	94	80	96
85	85	85	73	91	61	68	70	164	164	158	91	82	84
90	90	77	67	84	60	65	67	130	155	133	87	77	96
89	95	70	60	76	62	60	65	169	130	136	74	71	97
	100							131	173	139	84	83	86
	105							142	128	139	104	62	92
95	72	74	79	88	64	74	68	148	148	136	88	80	92
100		73	62	92	69	68	74						
105		69	62	73	55	52	58						
40	40	79	88	89	97	98	92	176	187	191	127	151	152
40	40	88	105	114	86	85	100	189	207	178	143	158	175
		Carbon Dioxide Production, Liters Per Hour											
40	40	53	64	66	61	68	58	200	182	164	88	102	105
50	50	61	70	71	66	66	65	198	184	193	95	90	112
60	60	62	59	73	65	61	67	191	168	167	101	84	112
70	70	68	56	83	58	63	67	178	174	176	90	86	104
80	80	67	58	74	58	64	65	191	151	163	86	74	92
85	85	78	73	87	60	65	70	170	152	155	76	76	89
90	90	72	66	83	55	62	68	125	135	114	80	76	106
89	95	59	60	76	61	62	64	130	113	101	63	62	94
	100							106	103	89	68	78	86
	105							115	97	100	77	58	71
95	72	76	71	89	67	70	68	149	155	122	82	83	89
100		62	57	70	72	70	66						
105		50	42	58	50	41	46						
40	40	80	79	89	90	85	90	180	196	187	111	119	138
40	40	81	95	105	80	82	91	189	217	178	121	128	152
		Methane Production, Liters Per Hour											
40	40	6.6	4.2	4.8	4.8	5.4	5.4	21.6	16.8	16.2	7.8	7.2	8.4
50	50	4.8	5.4	4.2	6.0	6.0	6.0	20.4	16.8	18.0	8.4	7.2	9.0
60	60	4.8	3.0	4.8	6.0	5.4	6.0	19.2	15.0	15.6	7.8	7.2	13.2
70	70	4.8	3.6	4.8	4.8	3.6	4.8	17.4	16.8	18.0	6.0	8.4	10.2
80	80	3.6	3.6	4.8	4.8	7.2	4.2	18.0	15.6	18.0	7.2	6.0	8.4
85	85	9.0	5.4	12.0	5.4	4.8	9.6	20.4	19.8	16.2	3.6	5.4	11.4
90	90	6.0	4.8	4.2	3.0	7.8	6.6	15.6	19.2	12.6	4.8	7.2	10.8
89	95	3.0	3.6	4.8	4.2	13.2	4.8	12.6	15.0	4.8	4.2	5.4	9.0
	100							19.8	16.8	5.4	4.8	4.8	13.8
	105							9.6	16.8	3.6	2.4	3.0	4.2
95	72	6.6	4.2	7.8	2.4	4.8	9.0	21.0	17.4	13.8	4.8	6.0	9.6
100		6.6	1.8	1.8	6.6	6.0	14.4						
105		0	2.4	0	3.0	3.0	0						
40	40	8.4	6.6	8.4	7.2	5.4	7.8	16.8	21.0	15.6	9.0	6.6	8.4
40	40	6.0	8.4	9.6	6.0	6.0	8.4	15.6	19.8	17.4	6.6	7.2	12.0

* See Table 1 for the number of observations in each average.

TABLE 6.--AVERAGE* METABOLIC WEIGHT LOSS PER ANIMAL FOR SUCCESSIVE TEMPERATURE LEVELS (OPEN-CIRCUIT METHOD)

Temperature Level, °F		HEIFERS						COWS					
		Brown Swiss			Brahman			Brown Swiss			Brahman		
Heifers	Cows	2	3	1	2	3	1	20	16	24	209	189	190
		Grams Per Hour											
40	40	27	33	20	29	32	28	144	119	92	46	46	71
50	50	29	33	34	38	37	39	132	122	141	55	56	71
60	60	26	28	38	39	36	36	135	101	95	55	41	73
70	70	32	25	34	36	32	32	111	99	89	39	42	54
80	80	29	25	34	35	41	31	145	81	96	41	36	51
85	85	39	44	51	36	35	45	116	80	91	23	37	64
90	90	36	38	47	25	36	43	72	59	44	38	45	81
89	95	19	36	45	35	46	38	24	48	10	22	26	53
	100							37	-31	-14	18	39	57
	105							31	21	2	5	28	12
95	72	49	30	56	43	36	43	99	107	57	40	54	52
100		24	25	8	48	45	34						
105		0	-4	11	22	9	8						
40	40	51	35	55	44	32	53	116	135	108	44	24	62
40	40	38	44	52	39	45	43	115	147	110	40	32	59

* See Table 1 for the number of observations in each average.

TABLE 7.--AVERAGE* PULMONARY VENTILATION RATE PER ANIMAL FOR SUCCESSIVE TEMPERATURE LEVELS (OPEN-CIRCUIT METHOD)

Temperature Level, °F		HEIFERS						COWS					
		Brown Swiss			Brahman			Brown Swiss			Brahman		
Heifers	Cows	2	3	1	2	3	1	20	16	24	209	189	190
		Liters Per Minute											
40	40	46	35	42	38	33	38	128	107	98	64	58	62
50	50	44	36	47	42	28	36	136	114	112	76	51	64
60	60	56	48	49	37	47	34	129	105	118	76	45	76
70	70	52	56	55	39	38	38	144	155	146	74	57	72
80	80	66	44	55	40	43	45	220	222	167	76	54	71
85	85	70	72	74	42	56	65	232	272	227	78	54	69
90	90	114	86	107	53	40	62	235	298	248	92	72	80
89	95	89	80	84	54	50	64	264	314	272	93	55	82
	100							334	282	236	140	80	122
	105							266	351	283	143	131	168
95	72	123	84	92	74	57	79	159	196	151	66	52	57
100		163	158	172	88	104	109						
105		148	180	188	106	104	122						
40	40	44	40	40	36	32	37	91	102	105	64	54	66
40	40	44	49	41	33	30	34	79	104	82	66	60	59

* See Table 1 for the number of observations in each average.