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Growth and Development

With Special Reference to Domestic Animals

LXV.

HEAT PRODUCTION AND CARDIORESPIRATORY ACTIVITIES DURING GESTATION AND LACTATION IN HOLSTEIN CATTLE

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I. INTRODUCTION

This report on the influence of gestation and lactation on the heat production and cardiorespiratory activities of *Holstein* cattle is a continuation of the preceding report (Missouri Res. Bull. 412, 1948) on the same subject concerned with *Jersey* cattle.

Since the theoretical, interpretive, methodological, and literature aspects of this problem have been discussed in Research Bulletin 412, the present report is confined almost entirely to the presentation of the new numerical data in the form of charts and tables.

II. DATA

As in Research Bulletin 412, so in this report, "resting heat production" represents the rate of oxygen consumption measured with the animal lying normally at rest under the usual commercial dairy-barn conditions[1] just before the morning feeding.

The heat production of a single Holstein heifer (Fig. 1) in relation to gestation and lactation is similar to that for a Jersey heifer (Fig. 4, Missouri Research Bulletin 412). For the Jersey we found that heat production per unit surface area during the lactation peak was approximately double that at the time of breeding; and the heat production per unit surface area near the end of the gestation period was approximately 40 per cent above the metabolic level at the time of breeding. The data for the Holstein heifer, Fig. 1, show a similar trend. The average percentage heat increments of gestation and

*The data here presented were obtained some years ago under the Herman Frasch Foundation tenure. This material was compiled at this time to help interpret data on the cardiorespiratory responses of dairy cattle to be obtained under various environmental temperatures in a cooperative project of this Station with the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture. D. M. Worstell represented the U.S.D.A. in this compilation.

[1]For the details of measuring oxygen consumption and heat production, see Chapter 12 in S. Brody's, "Bioenergetics and Growth." Reinhold Publishing Corporation, 1945.

lactation, as shown in Table 5, are considerably below those shown in Fig. 1 for an individual.

The *average* resting heat production per square meter per day of 13 Holstein heifers before breeding, during gestation, and during lactation, all plotted against the average body weight, is represented

TABLE 1. THE STANDARD DEVIATION AND STANDARD ERROR OF ESTIMATE FOR THE AVERAGE HEAT PRODUCTION OF THIRTEEN HOLSTEIN COWS PLOTTED IN FIG. 2.

Weight Interval lbs.	Number of Observations	Average Heat Production Cal./Sq. M./Day	Standard Deviation	Standard Error of Estimate
		Non-Lactating, Non-Gestating		
200-300	7	2065	103	38.9
300-400	23	2103	244	50.9
400-500	33	2073	259	45.1
500-600	30	2063	140	25.6
600-700	27	2183	123	23.7
700-800	34	2098	260	44.6
800-900	19	2023	303	69.3
900-1000	9	2092	222	74.0
		Gestation		
800-900	5	2319	92	41.1
900-1000	19	2086	178	40.8
1000-1100	24	2145	160	32.6
1100-1200	29	2212	345	64.1
1200-1300	36	2456	332	55.3
1300-1400	17	2671	371	89.9
1400-1500	10	3020	282	89.1
		Lactation		
800-900	6	2728	100	40.7
900-1000	25	2769	299	59.9
1000-1100	25	2870	304	60.8
1100-1200	51	2830	313	43.9
1200-1300	18	2797	317	74.7
1300-1400	28	3308	368	69.6

in Fig. 2. The standard deviations and standard errors of estimates around these average points are presented in Table 1.

The heat increments of gestation (broken curves) and lactation (continuous curves) of four of the Holstein heifers are presented in

Fig. 3. The magnitudes of the heat increments for the Holstein heifers —which vary with the milk-yield level—are roughly of the same order of magnitude as for the Jerseys—4,000 to 6,000 Calories per day at the lactation peak.

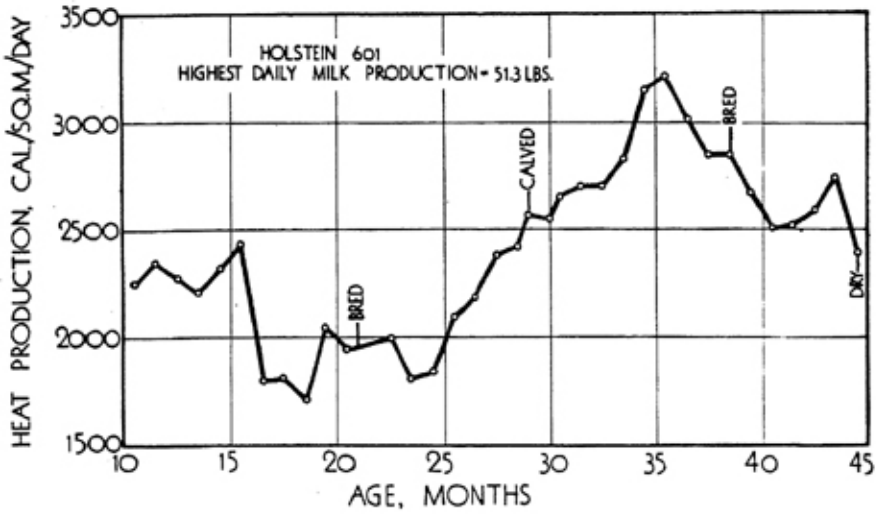

Fig. 1.—The influence of age, gestation, and lactation on the heat production per unit surface area in a typical Holstein heifer.

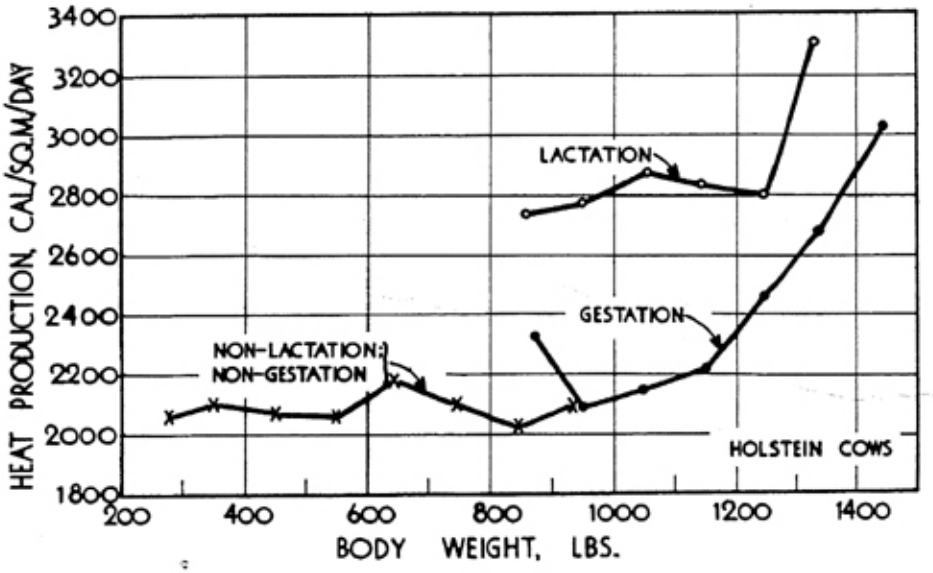

Fig. 2.—The *average* resting heat production per square meter surface area per day of 13 Holstein heifers before breeding, during gestation, and during lactation plotted against body weight. See Table 1 for the numerical values and statistical constants.

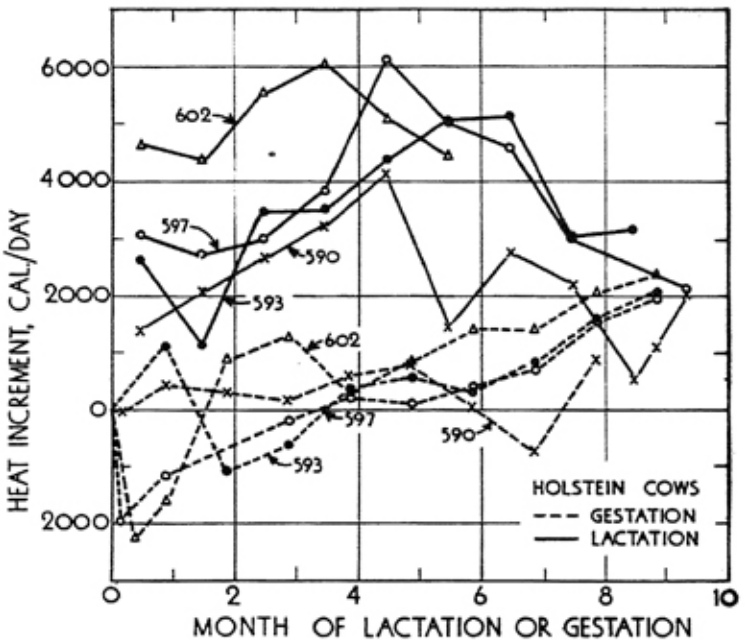

Fig. 3.—The heat increments of lactation (continuous curves) and of gestation (broken curves) of four individual Holstein heifers.

The *actual* metabolism level during gestation at various times (the data points) is compared with the *computed* non-gestating metabolism[2] in the *lower* half of Fig. 4 (plotted on a logarithmic grid).

The *upper* half of Fig. 4 similarly compares lactating metabolism (data points and the average continuous curve with equation) with the equation line for non-lactating and non-gestating metabolism. The difference between the two curves, of course, represents the heat increment of lactation. Note that the increment in this Holstein group of cattle increases with increasing size of the animals at a greater rate than for the Jerseys (Fig. 9 in Research Bulletin 412).

The pulse and respiration rates, as shown in Fig. 5, tend to follow a parallel age course, both declining from about the 90 rate level at birth to about 60 at 20 months (breeding time for the first gestation), then rising in parallel to 75 or 80 during late gestation and early lactation, and declining again to about 60 on drying off during early gestation. The respiration-pulse data are, however, complicated and confused by the superimposed seasonal-temperature rhythms, because respiration rate in panting animals is a vital body-temperature regulating mechanism and so varies sensitively with environmental temperature.

[2]Brody, S., Kibler, H. H., and Ragsdale, A. C., Resting Energy Metabolism and Ventilation Rate in Relation to Body Weight in Growing Holstein Cattle. Univ. Mo. Agr. Exp. Sta. Res. Bull. 350, Sept. 1942.

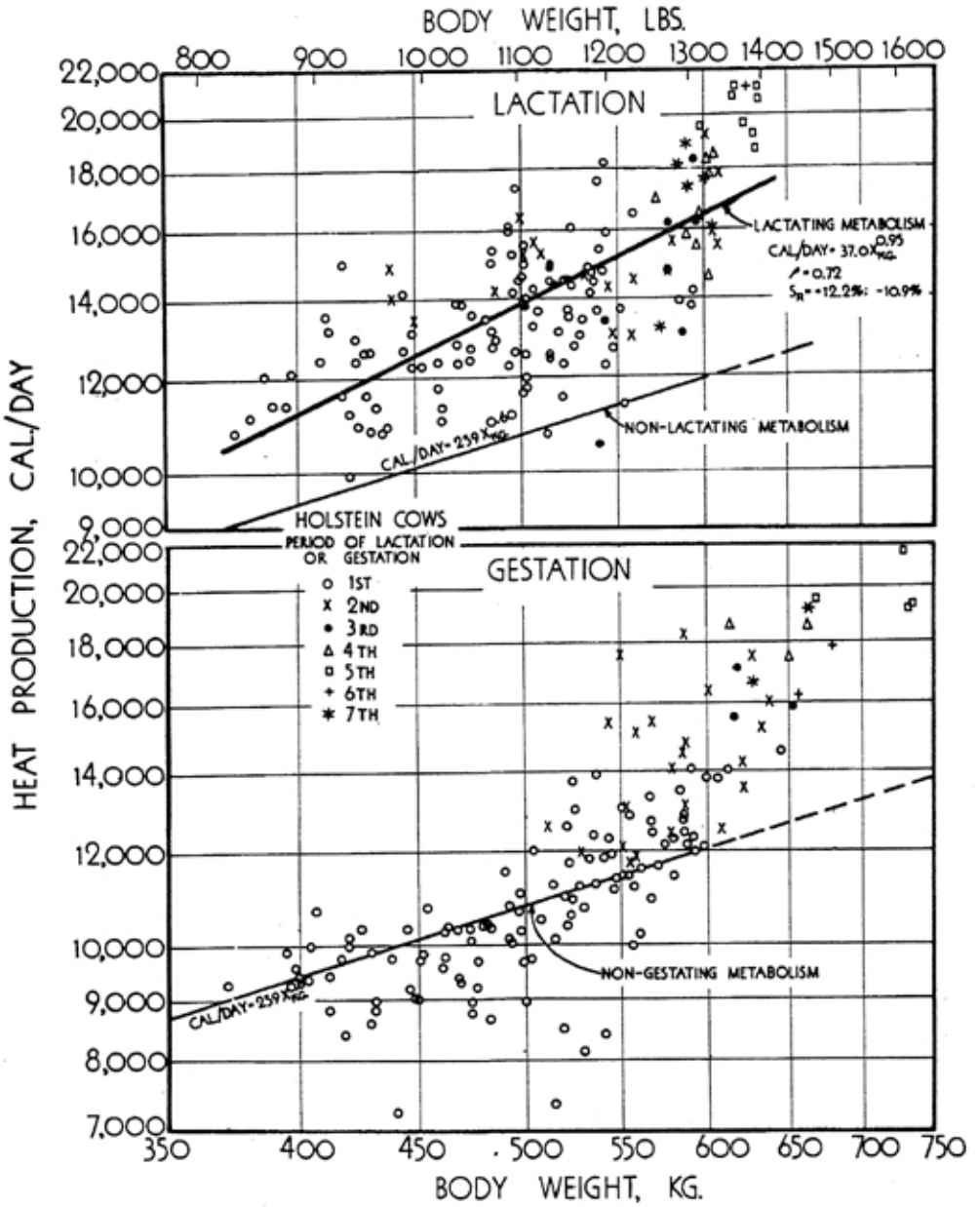

Fig. 4.—The *curve* in the *lower half* of the chart represents the non-gestating metabolism of Holstein cattle as function of live weight (See Mo. Res. Bull. 350, 1942); the *data points* represent observed metabolism during the first to the fifth gestation periods. The heavier (with calf) animals have relatively greater heat production. The *lower curve* in the *upper half* of the chart represents non-lactating metabolism as function of body weight; the *upper curve* represents lactating metabolism. All curves were fitted to the lactation data by the method of least squares. The difference between the lower and upper curves represents the heat-increment of lactation.

The ventilation rate (air inhaled per minute) parallels the total heat production, as might be expected, since the rate of heat production is dependent on the air supply. The total heat production and re-

spiration rates, of course, fluctuate with the gestation and lactation periods as explained in the introduction and in connection with Fig. 1. The resting heat production per square meter surface area per day seems to range from 1500 Calories in very young calves and 3500 Calories in mature lactating cows.

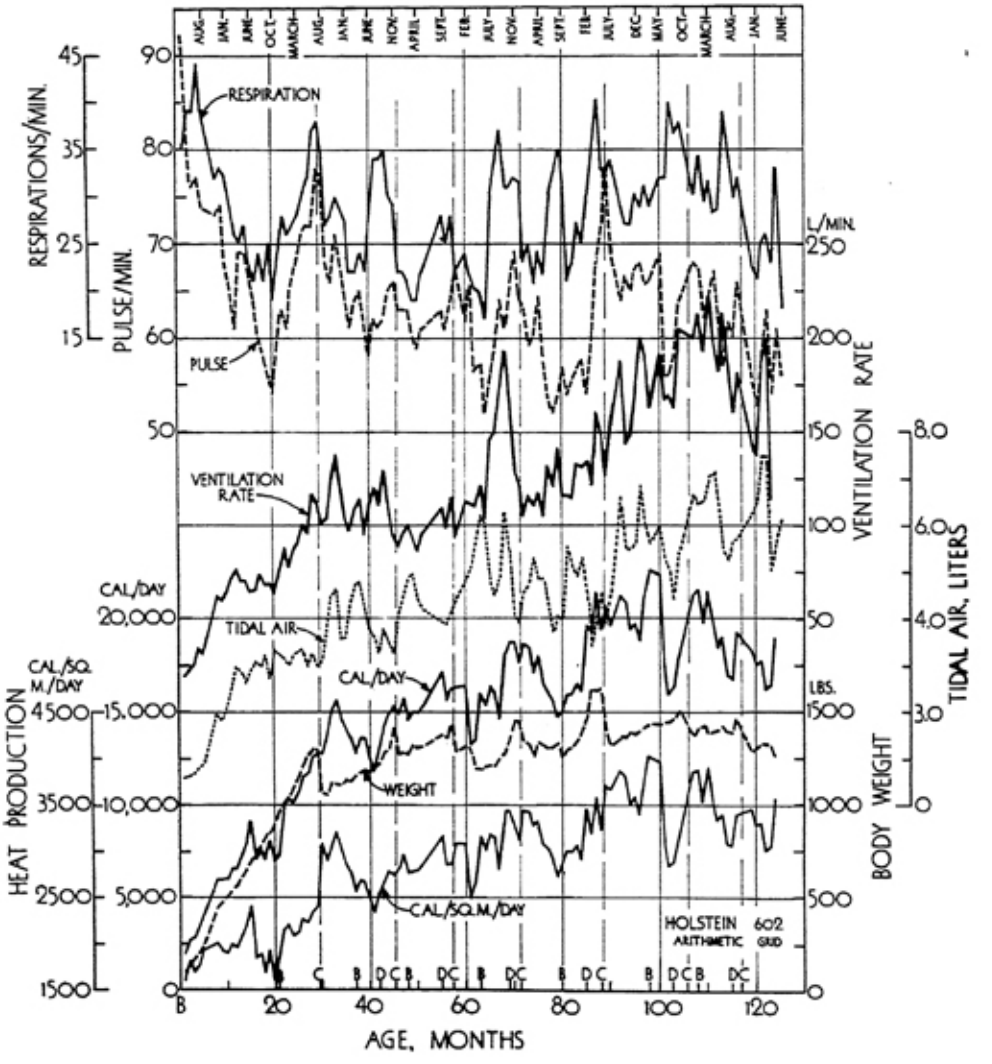

Fig. 5.—The cardiorespiratory activities follow a parallel course during growth, gestation, and lactation.

Fig. 6 represents the same data as Fig. 5, but on an arithlog grid on which parallel slopes represent equal *percentage* changes (in contrast to Fig. 5 in which parallel slopes represent equal *absolute* changes). The curves on the arithlog grid are less confused than on the arithmetic grid. As in Fig. 5, pulse and respiration rate follow

a parallel course. In Fig. 6, tidal air and ventilation rate show a better parallelism than in Fig. 5. The important idea brought out by Fig. 6 is the existence of an integrating parallelism between heat production and all other measurements and their parallel responses to gestation and lactation.

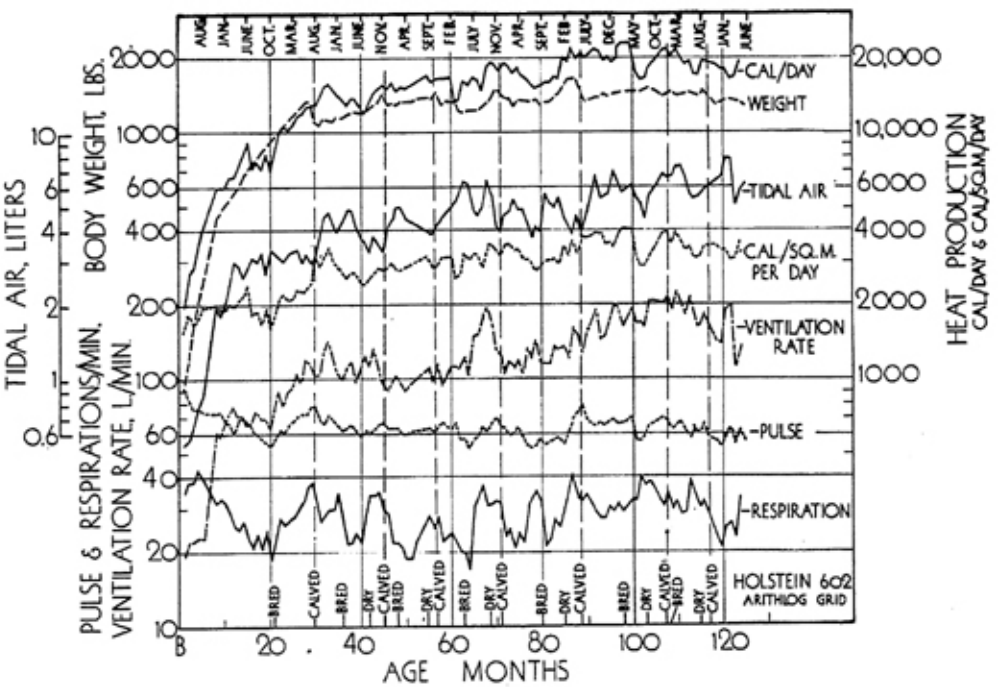

Fig. 6.—The same data as in Fig. 5 but plotted on an arithlog grid.

The various functions shown in Figs. 5 and 6 are represented in Fig. 7 in terms of percentages of the respective values at age 20 months, when most of the animals were bred for their first gestation period. Because the curves are so crowded and not easily followed, they are supplemented by the following statement and by Table 5. The ventilation rate reaches a peak of 350 per cent of the breeding (20-month) level; heat production, 325 per cent above the breeding level; Cal. sq. meter/day, 250 per cent; tidal air and respiration rate, 200 per cent; body weight, 170 per cent; pulse, 154 per cent.

The time course of the ventilation rate and of its two constituent factors, respiration rate (*intensity* factor) and tidal air (*capacity* factor), is represented for two cows in Fig. 8. The tidal air (capacity of lungs) tends to decline somewhat with the advancing gestation period, perhaps by crowding of the pregnant uterus, while the respiration rate tends to go up, perhaps by way of compensation. As

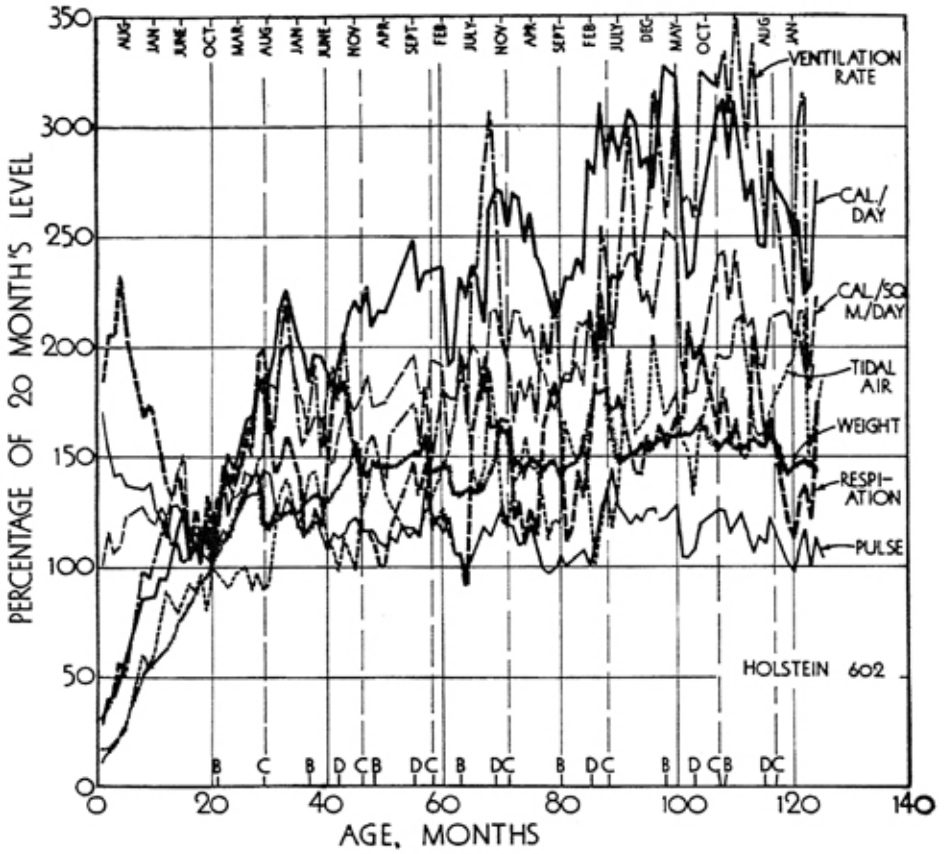

Fig. 7.—The same data as in Figs. 5 and 6 but plotted as percentages of the respective values at 20 months of age when most of the heifers were bred (See also Table 5).

previously noted, the respiration rate in cattle (and in other panting species) is confused by its body-temperature regulating function. Hence, the high respiration rates during July-August; also during productive peaks which increase heat production.

III. SUMMARY

Quantitative data are presented on the influence of gestation and lactation on the resting heat production, on body weight, and on the cardiorespiratory activities (pulse rate, tidal air, respiration rate, pulmonary ventilation rate) of 13 growing Holstein cattle.

This report on *Holstein* cattle is an extension of Missouri Research Bulletin 412 (on Jersey cattle) to which the reader is referred for the review of literature and interpretations, as the data here given for Holstein are similar to those given in Research Bulletin 412 on Jersey and the same interpretations hold for both. Table 5 is a summary comparison of the data on Jersey and Holstein cattle.

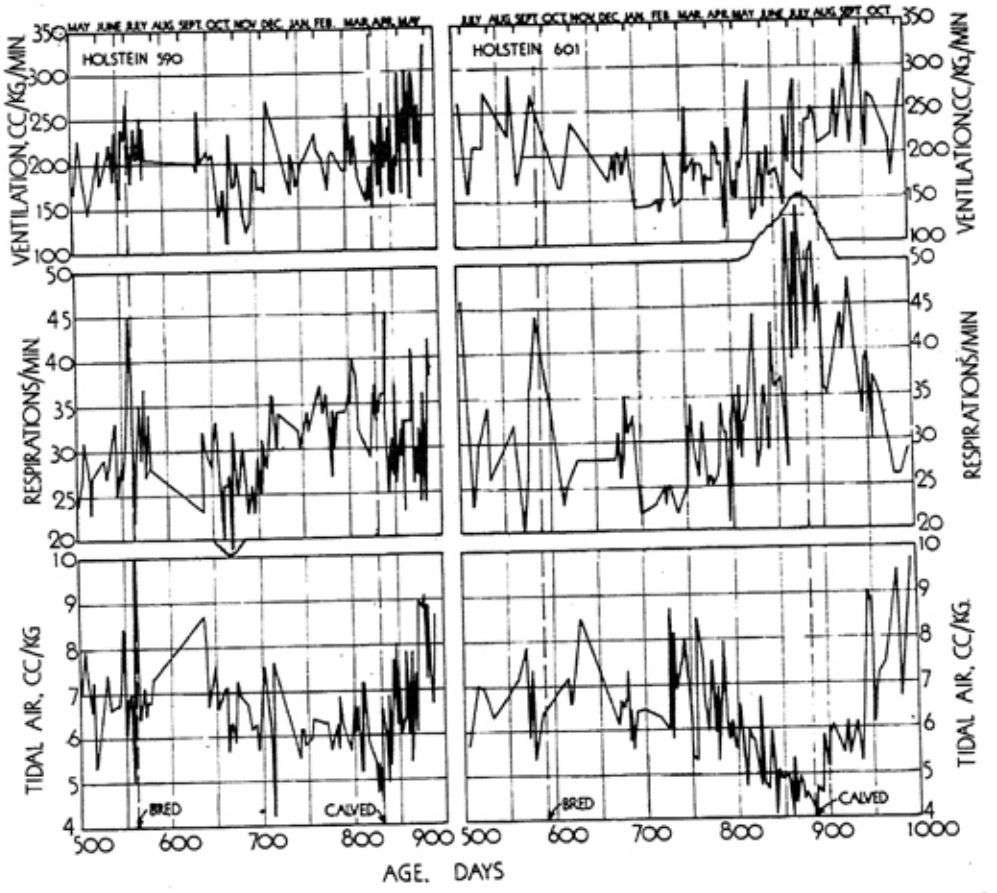

Fig. 8.—Interrelations between tidal air, respiration rate, and pulmonary ventilation rate during gestation and lactation of two Holstein heifers.

TABLE 2. HEAT PRODUCTION AND CARDIORESPIRATORY FUNCTIONS DURING GROWTH OF HOLSTEIN HEIFERS

(Values interpolated from charts of monthly observations; air volumes reduced to S.T.P.)

Animal No.:	590	591	592	593	596	597	599	600	601	602	603	604	669	Average
At Age Six Months														
Body weight, lbs.	330	290	260	320	320	260	300	250	290	300	---	290	360	298
Heat production, Cal./day:														
Per square meter	2200	2100	2160	2100	2220	2080	2000	1960	2040	1950	---	2180	2370	2113
Per animal	5500	5000	4660	5000	5500	4500	4800	4200	4700	4600	---	5100	6200	4980
Pulse per min.	80	--	74	74	75	78	71	72	64	74	---	95	73	75.4
Respirations per min.	33	39	34	29	35	36	24	30	33	36	---	29	33	32.6
Tidal air, liters	1.6	1.1	0.9	1.2	1.1	0.9	1.5	1.0	1.2	1.2	---	1.8	1.6	1.26
Ventilation rate:														
Liters per min.	53	45	30	34	40	33	36	31	38	44	---	52	49	40.4
Cu. ft. per min.	1.87	1.59	1.06	1.20	1.41	1.17	1.27	1.09	1.34	1.55	---	1.84	1.73	1.43
At Age Twenty Months (Approximate Age of Breeding for First Gestation Period)														
Body weight, lbs.	920	870	825	925	950	710	800	830	880	900	910	900	900	871
Heat production, Cal./day:														
Per square meter	2270	2300	2250	2300	1860	1950	1520	2040	2040	1600	2020	2000	2280	2033
Per animal	10000	9900	9300	10200	8400	7450	6200	8400	8800	6900	8800	8600	9950	8685
Pulse per min.	67	65	67	71	64	62	58	62	62	54	64	63	65	63.4
Respirations per min.	31	24	20	23	30	24	22	25	33	19	30	22	32	25.8
Tidal air, liters	2.9	3.4	2.8	3.2	3.0	2.4	2.6	3.0	3.4	3.3	3.1	3.2	2.6	3.0
Ventilation rate:														
Liters per min.	90	81	56	75	90	58	56	76	100	68	95	70	84	76.8
Cu. ft. per min.	3.18	2.86	1.98	2.65	3.18	2.05	1.98	2.68	3.53	2.40	3.35	2.47	2.97	2.71

TABLE 3. HEAT PRODUCTION AND CARDIORESPIRATORY FUNCTIONS DURING THE NINTH MONTH OF THE FIRST GESTATION PERIOD OF HOLSTEIN CATTLE

(Air volumes reduced to S.T.P.)

Animal No.:	590	591	592	593	596	597	599	600	601	602	603	604	669	Average
Age, months	28	27	28	28	30	31	30	30	30	29	29	30	35	29.6
Body weight, lbs.	1360	1250	1160	1240	1440	1170	1270	1190	1300	1290	1330	1280	1320	1277
Heat production, Cal./day:														
Per square meter	2370	2420	2580	2430	2680	2340	2300	2360	2560	2400	2530	2330	2600	2455
Per animal	13000	12600	13000	12700	14600	11800	12100	12000	13700	12800	13800	12300	14000	12954
Heat increment of gestation, Cal./day/animal	1230	1400	1960	2070	3090	1940	2420	1160	2380	2390	2760	840	2560	2015
Pulse per min.	83	81	80	80	78	81	80	81	76	76	82	78	78	79.5
Respirations per min.	35	29	36	35	31	26	27	33	45	39	38	26	36	33.5
Tidal air, liters	3.5	3.5	3.0	3.0	3.5	3.8	3.4	2.9	2.7	3.0	3.0	4.0	2.4	3.21
Ventilation rate:														
Liters per min.	120	101	102	102	108	94	90	94	121	115	112	103	86	104
Cu. ft. per min.	4.24	3.57	3.60	3.60	3.81	3.32	3.18	3.32	4.27	4.06	3.96	3.64	3.04	3.66

TABLE 4. HEAT PRODUCTION AND CARDIORESPIRATORY FUNCTIONS DURING THE FIRST LACTATION PERIOD OF HOLSTEIN CATTLE

(Air volumes reduced to S.T.P.)

Animal No.:	590	591	592	593	596	597	599	600	601	602	603	604	669	Average
Values During the First Month Following Calving														
Body weight, lbs.	1215	1070	1010	1130	---	870	1020	920	1080	1070	1140	---	1240	1070
Heat production, Cal./day:														
Per square meter	2420	2650	2650	2560	---	2680	2380	2800	2530	3070	2810	---	2840	2672
Per animal	12400	12700	12300	12700	---	11400	11100	12400	12200	12800	14000	---	14800	12618
Heat increment of lactation, Cal./day/animal	1410	2370	2140	2620	---	3060	2500	3000	1990	4640	3930	---	3770	2857
Pulse per min.	72	73	70	74	---	77	75	79	67	77	82	---	74	74.5
Respirations per min.	32	30	34	32	---	35	33	35	44	34	37	---	35	34.6
Tidal air, liters	3.6	4.1	3.6	3.4	---	3.8	2.8	3.3	2.5	3.1	3.8	---	3.3	3.39
Ventilation rate:														
Liters per min.	115	120	116	107	---	115	92	103	110	101	141	---	115	112
Cu. ft. per min.	4.06	4.24	4.10	3.78	---	4.06	3.25	3.64	3.88	3.57	4.98	---	4.06	3.97
Values During the Month of Lactational Peak in Heat Production														
Age, months	32	29	34	34	---	36	34	34	36	33	33	35	38	34.0
Month of lactation	4	2	6	6	---	5	4	4	6	4	3	5	2	4.2
Body weight, lbs.	1110	1030	1090	1190	---	925	1000	940	1070	1110	1180	1120	1190	1080
Heat production, Cal./day:														
Per square meter	2920	2960	3300	3050	---	3350	2670	2920	3200	3200	2960	3400	3480	3118
Per animal	14300	13900	16000	15500	---	14800	12300	13000	15450	15600	14900	16600	17700	15004
Heat increment of lactation, Cal./day/animal	3787	3787	5388	5160	---	6140	3810	3510	5180	6090	4740	6050	6920	5047
Pulse per min.	78	76	68	71	---	69	68	70	60	71	67	72	75	70.5
Respirations per min.	35	42	29	28	---	28	27	34	36	30	31	24	33	31.4
Tidal air, liters	4.3	3.9	3.6	4.0	---	5.2	3.6	3.6	4.1	4.6	4.5	4.8	4.7	4.24
Ventilation rate:														
Liters per min.	146	170	105	115	---	144	97	119	150	138	143	118	154	133
Cu. ft. per min.	5.16	6.00	3.71	4.06	---	5.08	3.42	4.20	5.30	4.87	5.05	4.17	5.44	4.70
Milk yield, FCM, lbs./day, during second month of lactation	34.7	38.3	36.2	37.2	---	35.5	32.2	35.0	41.6	37.5	36.8	44.8	40.1	37.5

TABLE 5. COMPARISON OF CARDIORESPIRATORY ACTIVITIES FOR JERSEY AND HOLSTEIN CATTLE*

	Age six months	Breeding level	Ninth month of gestation	First month of lactation	"Lactational Peak"
Absolute Values					
Body weight, lbs.					
Jersey	217	597	926	844	842
Holstein	298	871	1277	1070	1080
Pulse per min.					
Jersey	76.7	64.4	80.4	79.3	79.5
Holstein	75.4	63.4	79.5	74.5	70.5
Respirations per min.					
Jersey	32.9	22.9	31.8	33.0	34.2
Holstein	32.6	25.8	33.5	34.6	31.4
Tidal air, liters					
Jersey	0.93	2.31	2.51	2.70	3.32
Holstein	1.26	3.00	3.21	3.39	4.24
Ventilation rate, l./min.					
Jersey	28.9	52.5	77.8	87.3	112
Holstein	40.4	76.8	104	112	133
Heat production, Cal./day					
Jersey	4097	7216	9762	10060	12024
Holstein	4980	8685	12954	12618	15004
Heat production, Cal./ Sq. M. per day					
Jersey	2087	2068	2211	2390	3003
Holstein	2113	2033	2455	2672	3118
Percentage Values of Breeding Level (18 and 20 Months of Age)					
Body weight, lbs.					
Jersey	36.3	100	155	141	141
Holstein	34.2	100	147	123	124
Pulse per min.					
Jersey	119	100	125	123	123
Holstein	119	100	125	118	111
Respirations per min.					
Jersey	145	100	139	144	149
Holstein	126	100	130	134	122
Tidal air, liters					
Jersey	40.3	100	109	117	144
Holstein	42.0	100	107	113	141
Ventilation rate, l./min.					
Jersey	55.0	100	148	166	213
Holstein	52.6	100	135	146	173
Heat production, Cal./day					
Jersey	56.8	100	135	139	167
Holstein	57.3	100	149	145	173
Heat production, Cal. per Sq. M. per day					
Jersey	101	100	107	116	145
Holstein	104	100	121	131	153

*Absolute values for Holstein data from Tables 2, 3, and 4 of this bulletin; Jersey data from similar tables in Res. Bul. 412.