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Growth and Development

With Special Reference to Domestic Animals

LXIII. Heat Production and Cardiorespiratory Activities During Gestation and Lactation in Jersey Cattle

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ABSTRACT

The peak of the "resting" heat production during lactation in Jersey cattle, and also in rats, is, per unit surface area, nearly twice as great as during the non-lactation period at the time of breeding for the first gestation. The "resting" pulse rate, respiration rate, pulmonary ventilation rate, and tidal air roughly parallel the resting heat production during gestation and lactation except that there is some tendency for the tidal air to decline somewhat during the last third of the gestation period with a compensatory increase in respiration rate. These statements are demonstrated by two tables of numerical values and illustrated by thirteen charts.

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I. INTRODUCTION

The heavily lactating animal is on a much higher metabolic plane than the non-lactating: it consumes two to three times as much food with an associated heat increment of feeding; its endocrine system, including the pituitary, adrenal, and thyroid, is more active; the mammary gland is enlarged and more active; the milk precursors in the blood are reorganized into milk (contrasted to blood, cow's milk contains about 90 times more carbohydrate, 20 times more fat, 14 times more calcium, 7 times more potassium, 4 times more magnesium, half the proteins, a fourth as much chloride, and an eighth as much sodium; milk also contains casein, lactose, and short-chain fatty acids which are not found in blood). These and related processes increase the heat production (oxygen consumption) and related cardiorespiratory activities of the lactating animal. It is, therefore, expected that a lactating animal would produce considerably more heat than a non-lactating one.

Lusk[1] concluded that ". . . lactation does not increase heat production . . . since the arrangement of food materials in the preparation of milk depends on hydrolytic changes and snytheses which involve hardly any thermal action." This conclusion, generally quoted in textbooks, is, however, based on heat production under basal conditions when the lactation rate is greatly depressed and the heat increment of feeding is eliminated, whereas we are here concerned with the *overall* heat increment of normally-fed animals.

*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.

1Lusk, G. "The Science of Nutrition," 1928, page 529.

It would be interesting to re-investigate the problem on man, in the light of our data on cattle, to measure the heat production and other cardiorespiratory activities at various intervals after a standard meal in lactating and non-lactating women, and also at various intervals after removing the milk since the rate of milk production declines rapidly with time after milking, as illustrated in Fig. 1 for a dairy cow, and with time after feeding as previously demonstrated[2] on dairy cattle and rats.

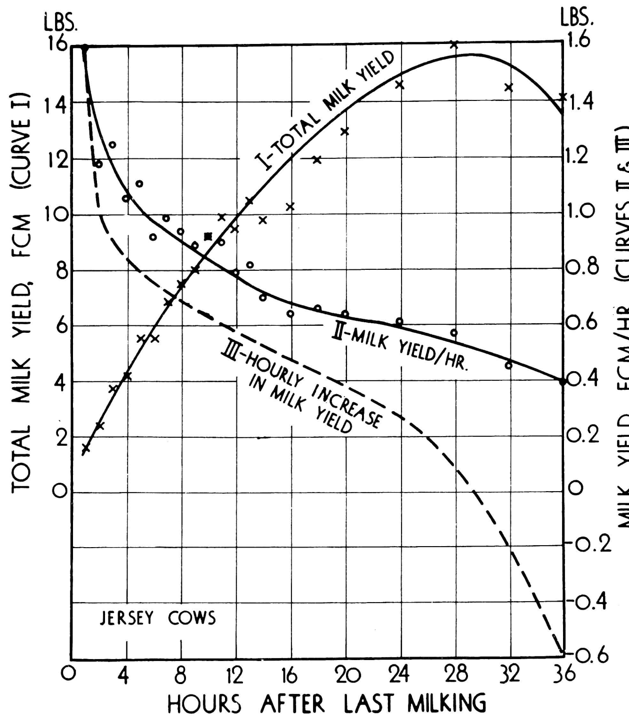

Fig. 1.—The milk (FCM) yield per hour declines with the lengthening of the time interval between milkings. The rising Curve I represents the total yield for the entire time interval shown on the time axis, up to 1, 2, 3 . . . 36 hours after the last milking; the declining Curve II represents the average hourly yield obtained by dividing the total yield (Curve I) by the hours in the interval after milking; Curve III represents the milk increment or decrement obtained by subtracting the yield for a given interval, such as 20 hours, from the next higher interval, such as 21 hours. Following the 28th hour the absolute milk yield (Curve I) in these cows decreased; the animals were "drying up" as result of delayed milking.

2Brody, S., "Bioenergetics and Growth," Reinhold Publishing Corporation, 1945, pp. 827-830.

II. DATA

In a preceding report[3] we presented data on heat production and pulmonary ventilation rate of Jersey cattle up to 24 months of age. The data in this bulletin are on the same group of Jersey heifers but emphasis is placed upon the gestation and lactation periods, that is, for the time following 24 months of age..

While our concern is with dairy cattle, preliminary observations were made on rats. Fig. 2 is a typical illustration of the influence of gestation and lactation on the body weight and heat production of a rat during two such periods. The total body weight (including the pregnant uterus) increased with the advance of the period of gestation, especially during the third (last) week. Just before parturition the body weight, during both the first and second gestations, was about 40 per cent above the breeding weight level.[4] About three-fourths of this 40 per cent body gain was lost on parturition and

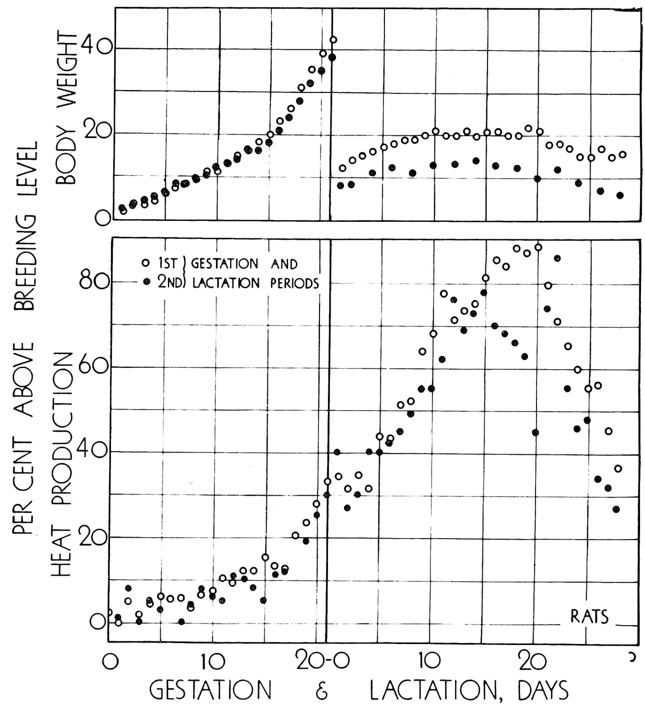

Fig. 2.—The influence of gestation and lactation on body weight and heat production in a rat.

[3]Brody, S., Kibler, H. H., and Ragsdale, A. C., Resting Energy Metabolism and Ventilation Rate in Relation to Body Weight in Growing Jersey Cattle, with a Comparison to Basal Energy Metabolism in Growing Man, Univ. Mo. Agr. Exp. Sta. Res. Bull. 335, Dec. 1941.

[4]Ref. 2, pp. 431-4.

one-fourth retained, presumably as growth in the young mother, a growth probably stimulated by pregnancy as suggested by Bogart[5] and others.

Lactation did not seriously affect the *body weight* of this rather well-fed rat, but it did increase the *heat production* about 90 per cent above the breeding level and 60 per cent above the gestation peak (Fig. 2).

The increased heat production with advancing gestation does not represent the heat increment of feeding (SDA) because gestation does not, apparently, increase the food consumption substantially as illustrated in Fig. 3 on rats, plotted from data by Wang[6], and as inferred from Eckles' observation[7] that cattle gain the usual 16 per cent in body weight during gestation on a maintenance ration. Fig. 3 illustrates a dramatic decline in muscular activity following breeding,

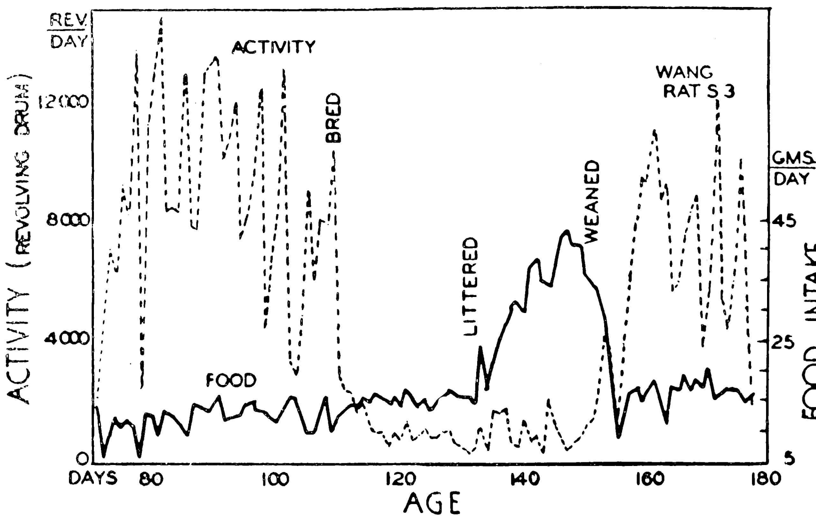

Fig. 3.—The influence of gestation and lactation on physical activity and on food consumption in the rat.

which lasts through gestation and lactation. The saving in energy involved in the decreased muscular activity probably suffices to supply the energy in the weight increase during pregnancy. This weight increase during pregnancy includes but little energy; the 57 kilogram weight loss on calving in a Jersey cow contains only about 11 kilogram dry matter. We, therefore, conclude that the increase in heat pro-

5Bogart, R., Sperling, G., Barnes, L. L., and Asdell, S. A., Am. J. Physiol., *124*, 363, 1940, and Cornell Univ. Memoir, 238, 1941.

6Wang, G. H., Am. J. Physiol. *71*, 736, 1925; Comp. Psychol. Monogr. *2*, #6, 1923. Slonaker, J. R., Am. J. Physiol., *71*, 363, 1924-5.

7Eckles, C. H., Univ. Missouri Agr. Exp. Sta. Res. Bull. 26, 1916. Hansson, A., "Droktighetens inverkon pai Kornas Levande Vikt" Sartryck ur Kungl. Lantruks Akodemieus Tidskrift. Agr. LXXXIV 368, 1945. For a numerical summary of the composition of calf, placenta, and amniotic fluid, see Ref. 2, pp. 436-7.

duction during gestation is not due to the heat increment of feeding, but to the increase in living tissue of the pregnant uterus and growing mother[8], and to endocrine influences, especially of the thyroid[8, 9].

III. ANALYZING RESTING HEAT PRODUCTION AND CARDIO-RESPIRATORY DATA OF JERSEY CATTLE

Resting heat production, as here defined, was computed from oxygen consumption, measured with the animal lying at rest under usual commercial dairy barn conditions[10]. As the animals were not fasted, the heat production included the heat increment of feeding (SDA). The measurements were made before the morning feeding but as it takes 48 to 72 hours for a cow to attain the postabsorptive state, the metabolic values before the morning feeding do not represent "basal metabolism," but simpy "resting metabolism," a fairly reproducible state even if not as sharply reproducible as the "basal metabolism."

A. Heat Production During Gestation and Lactation: Fig 4, which represents the heat production of a single Jersey heifer, typifies

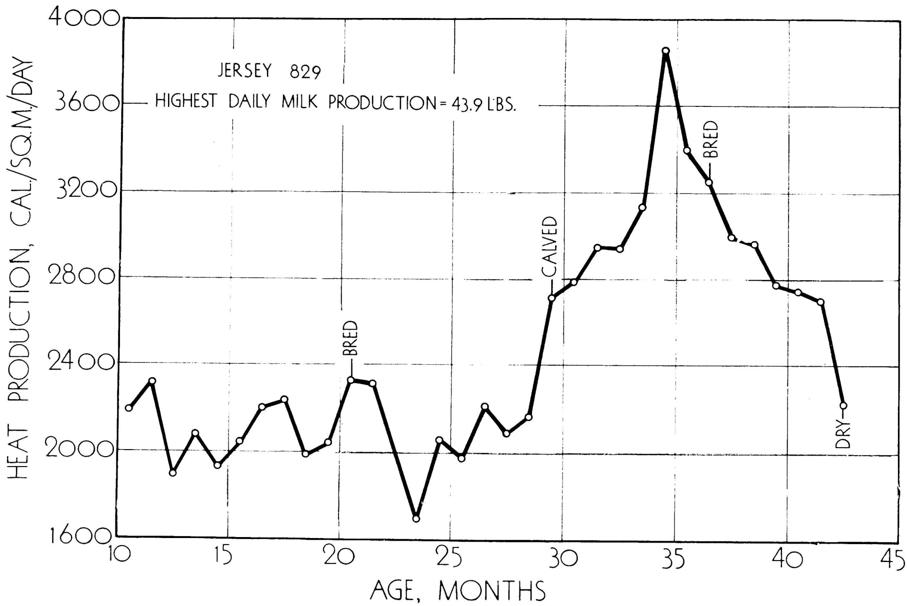

Fig. 4.—The influence of age, of gestation, and of lactation on the heat production per unit area in a typical Jersey heifer, plotted against time.

[8]Root, H. F., and H. K., Arch. Int. Med., *32*, 411, 1923. Johnston, J. A., Macy, I. G., *et al.*, J. Nutr., *15*, 513, 1938. Boyd, E., J. Nutr. *5*, 551, 1932.

[9]Schwartz, O. H., and Drabkin, C., Am. J. Obs. & Gyn., *22*, 3, 1931.

[10]For methods of measuring oxygen consumption, see Chapter 12, especially the figures on pp. 313-19, Ref. 2.

the influence of the first gestation and lactation periods on the resting heat production per unit surface area of Jersey cattle in general. Prior to breeding for the first gestation, the heat production of this heifer was about 2000 Calories per square meter per day; a slight

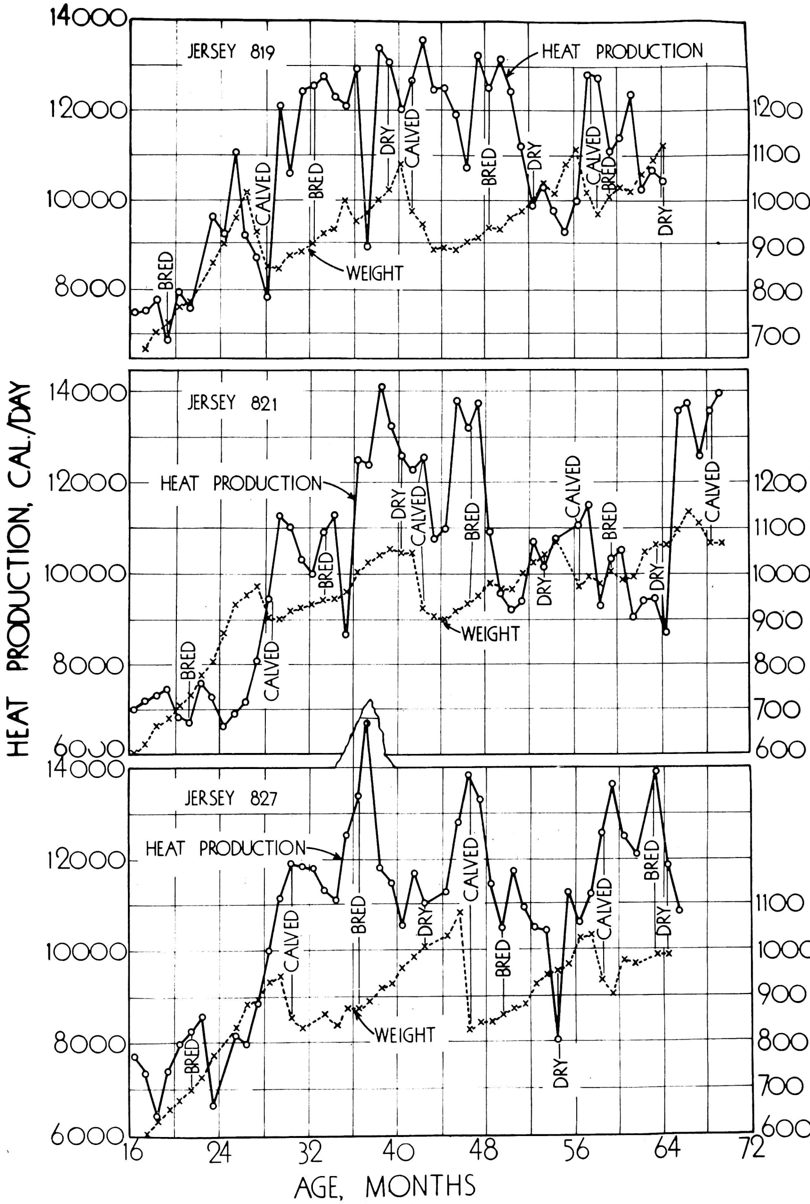

Fig. 5.—Resting heat production and body weight as function of age, gestation, and lactation.

decline in resting heat production followed during the first three months of gestation (which agrees with the observation of Ritzman and Benedict[11]) ; this was followed by a rise to a peak of near 2800 Calories per square meter per day shortly before calving (contrasted to the 2000 Calories at breeding time) ; and finally the lactation heat production peak of about 3800 Calories per square meter per day was reached (which is a 90 per cent heat increment above the breeding level, identical with the lactation heat increment peak observed on the rat in Fig. 2). The near quantitative identity between the heat incre-

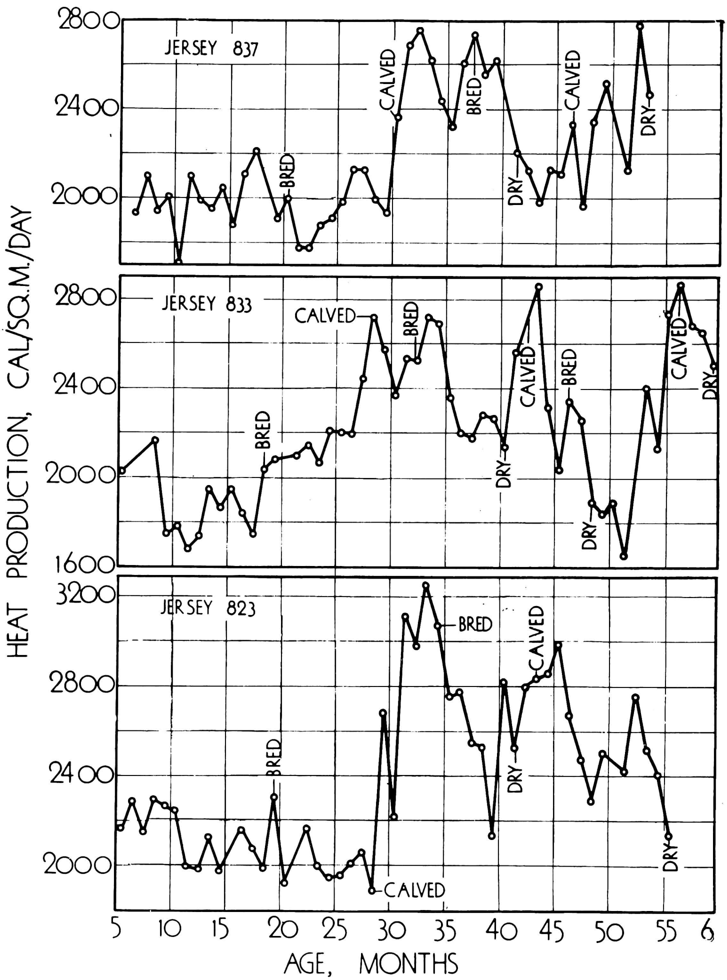

Fig. 6.—Resting heat production, Calories per square meter per day, as function of age, gestation, and lactation.

[11]Ritzman, E. G., and Benedict, F. G., New Hampshire Agr. Exp. Sta. Tech. Bull. 45, 1931.

ment of lactation in good dairy cows and in rats is significant. Similar results were obtained on other cows as shown in Figs. 5 and 6 in which the total Calories per day, Calories per square meter per day, and body weight were plotted against age.

Fig. 7 represents the average resting heat production per square meter per day of 16 Jersey heifers plotted against body weight (instead of against age as in Fig. 4). Here again there seems to be an initial decline in the heat production of gestation followed by a

TABLE 1. THE STANDARD DEVIATION AND STANDARD ERROR OF ESTIMATE FOR THE AVERAGE HEAT PRODUCTION OF THE SIXTEEN JERSEY COWS PLOTTED IN FIG. 7.

Weight Interval lbs.	No. of Observations	Average Heat Production Cal./sq.m./day	Standard Deviation	Standard Error of Estimate
		Non-Lactating, Non-Gestating		
200-300	36	2072	226	37.6
300-400	47	2009	202	29.5
400-500	53	1987	195	26.7
500-600	43	1994	176	26.8
600-700	26	2060	126	24.8
700-800	3	1921	32	18.4
		Gestation		
500-600	5	2173	344	153.8
600-700	18	2127	235	55.3
700-800	48	1954	159	23.0
800-900	39	2077	252	40.3
900-1000	59	2193	423	55.1
1000-1100	41	2349	285	44.5
1100-1200	13	2510	300	83.1
		Lactation		
600-700	7	2568	170	64.4
700-800	27	2600	304	58.6
800-900	74	2701	354	41.1
900-1000	74	2728	432	50.2
1000-1100	25	2702	292	58.4
1100-1200	6	2640	79	32.4

rise during the latter months. The average gestational peak in heat production is similar to the individual cow in Fig. 4; but the average lactational peak is much lower, probably due to some cancelling out of the peaks and troughs in the averaging process. The value for the standard deviations and standard error of estimate around these average points are presented in Table 1.

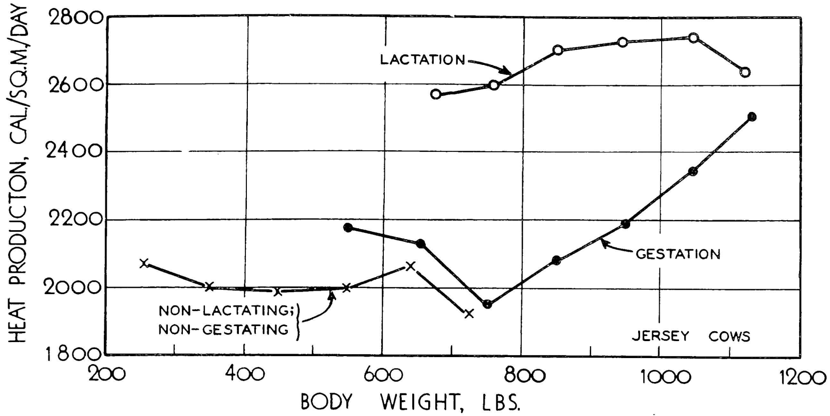

Fig. 7.—The influence of age, gestation, and lactation on the *average* heat production per unit area of a herd of 16 Jersey heifers plotted against body weight. The standard deviations and standard error of estimates are shown in Table 1.

B. Heat Increments of Gestation and Lactation: Fig. 8 shows that the heat increment of gestation is rather slight, and that only during the last few months does it become appreciable; the heat increment of lactation, attained about three months after calving, is, on the other hand, quite considerable—between 3000 and 4000 Calories per day, although the average heat increment is of the order of only 2000 Calories per day.

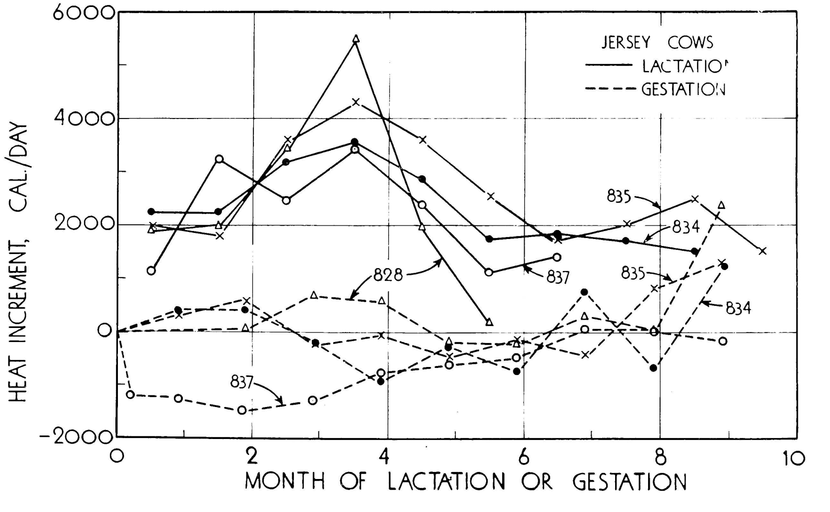

Fig. 8.—Total heat increments of lactation and gestation of four individual Jersey heifers. For method of computing the heat increments, see page 12 of text.

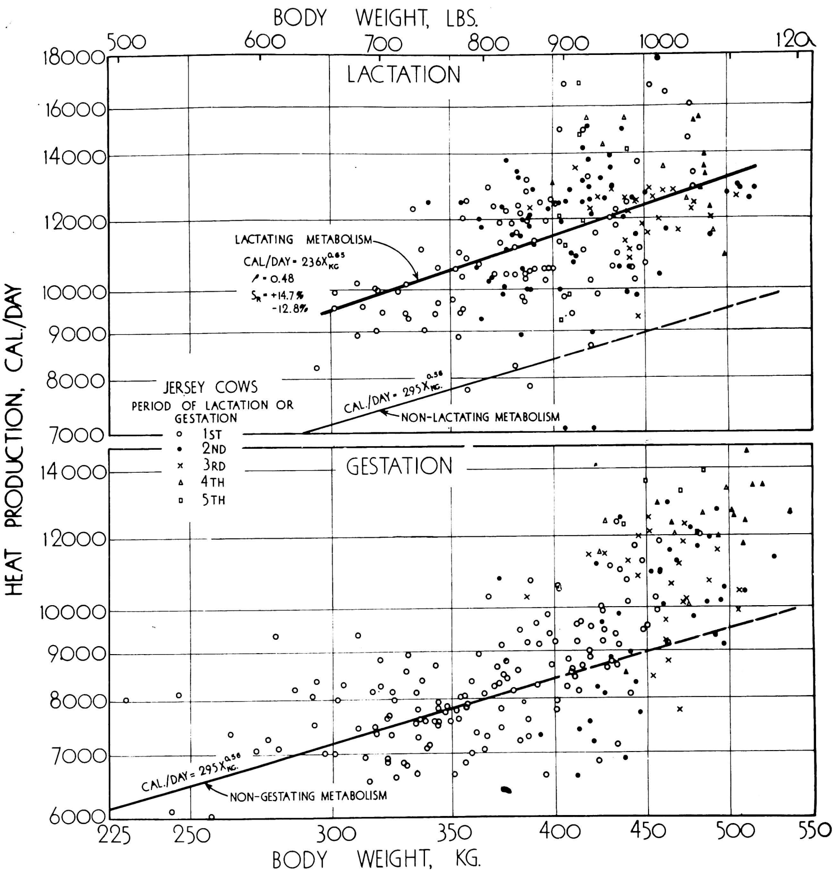

Fig. 9.—The continuous curve in the *lower half* of the chart represents the non-gestating metabolism of Jersey cattle as function of live weight (see Mo. Agr. Exp. Sta. Res. Bull. 335, 1941); the data points represent observed metabolism during the first to the fifth gestation periods. Note the relatively greater heat production in the heavier (with calf) animals. The lower continuous curve in the *upper half* of the chart represents non-lactating metabolism as function of body weight and the upper curve was fitted to the lactation data. At 400 kg. body weight the heat production during lactation was 37 per cent above that of the non-lactation (11596 — 8453) ÷ 8453 = 37.2%.

The heat increments were computed as follows: First, the average heat production per unit surface area was computed for the period 6 months to the time of breeding for the first gestation (approximately 18 months). This average value was used as a base value to obtain the heat increments associated with the different periods of gestation and lactation. The heat increment in total Calories per day per animal was then obtained by multiplying the heat increments in Calories per square meter per day by the surface area in square meters for the corresponding months of gestation or lactation. This method of computation is justified by the approximately constant value of heat production per square meter of surface area from 6 to 24 months of age[3].

C. Heat Production as Function of Body Weight: The continuous line in the lower half of Fig. 9 represents the non-gestating metabolism of growing Jersey heifers[3] for the weight range 225 to 450 kg (500 to 900 lbs.) and the data points represent monthly averages of metabolic observations on individual gestating animals during the first to the fifth gestation periods. The upper half similarly represents the lactation metabolism; both charts are plotted on logarithmic grids.

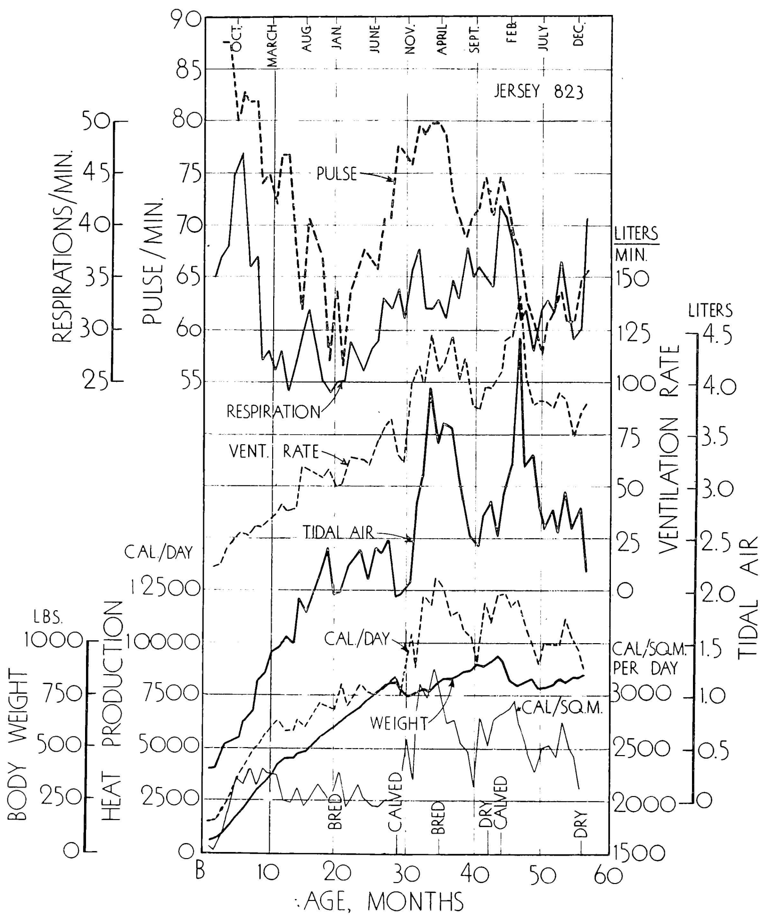

Fig. 10.—The absolute values of the cardiorespiratory activities and heat production as function of age, gestation, and lactation, in Jersey heifer 823, plotted on arithmetic grid.

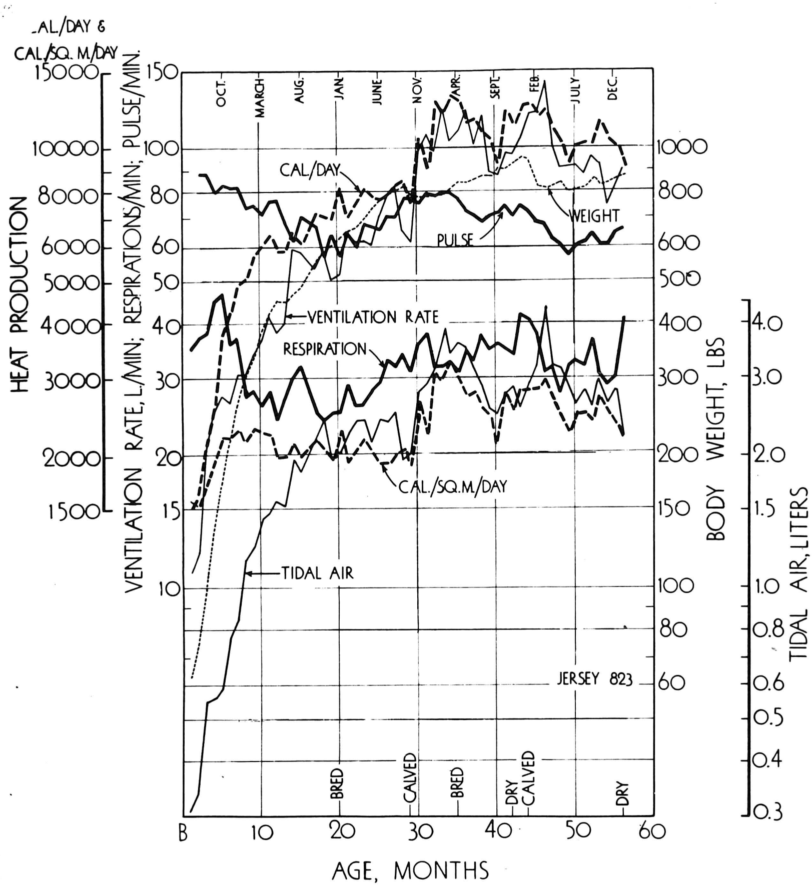

Fig. 11.—The same data as in Fig 10 plotted on an arithlog grid.

The average percentage difference between lactation and non-lactation metabolism is, of course, much less when computed by the logarithmic method from Fig. 9 (37 per cent at 400 kg body weight) than by the arithmetic method from individual animals in Figs. 2 and 4 (nearly 90 per cent)[12].

D. The Relative Time Trends of the Several Cardiorespiratory Activities: These are illustrated for Jersey heifer 823 in Figs. 10, 11, and 12, and numerical values for all cows are given in Tables 2 and 3. Fig. 10, plotted on arithmetic paper, shows that the pulse and respiration rates tend to decline from birth to about 18 months (when the animals were bred) and rise during gestation and lactation in roughly

12For a detailed discussion of differences in results obtained by the arithmetic and logarithmic methods of computing percentage differences, see the discussion in connection with the chart on page 494, Ref. 2.

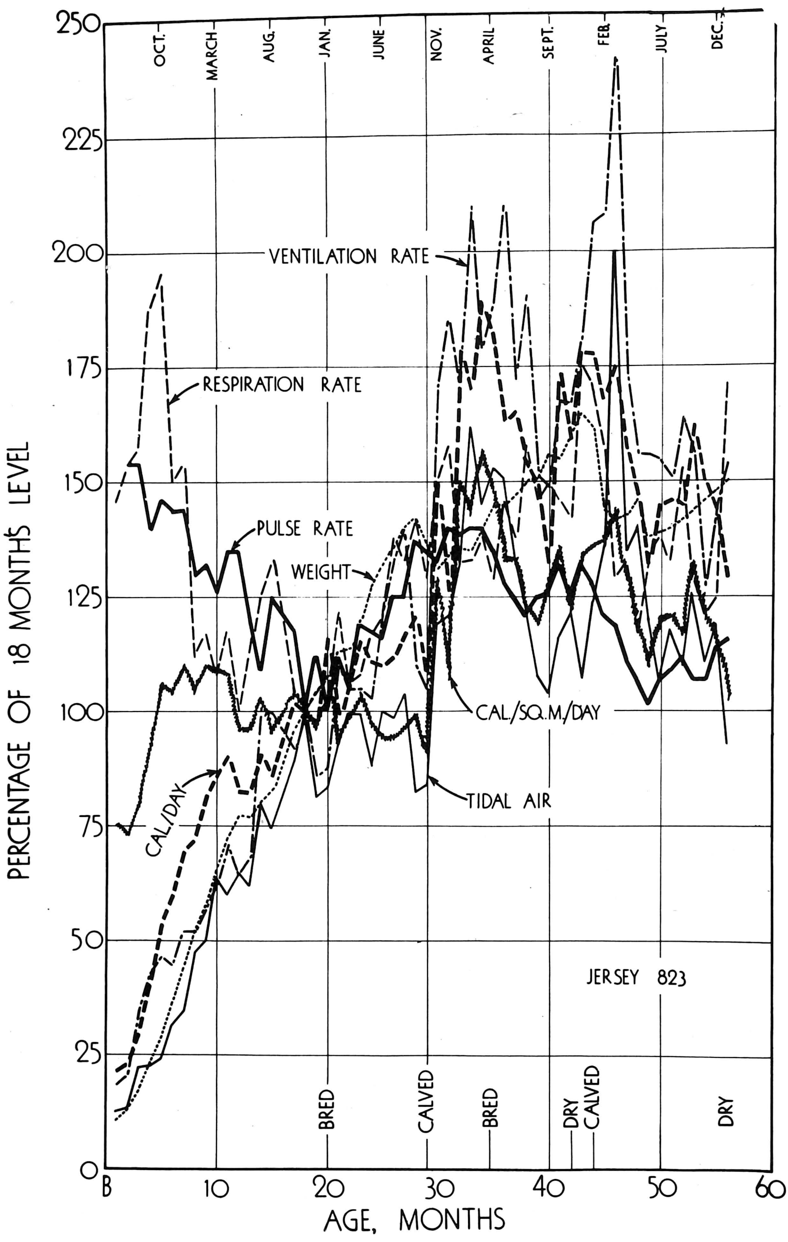

Fig. 12.—The same data as in Figs. 10 and 11 plotted in terms of the percentage values of the various functions at 18 months of age, the time most of the heifers were bred for their first gestation.

parallel manner. The pulmonary ventilation rate (air exhaled or inhaled per minute), heat production, and body weight, all rise from birth on with superimposed increments during gestation and lactation. The heat production per unit surface area rises from birth until about six months, remains roughly constant from ten months to breeding for the first gestation, then changes as explained in connection with Fig. 4. The tidal air (air exhaled or inhaled per respiration) roughly parallels the ventilation rate and heat production, except that during gestation the rise in tidal air tends to fall below the other cardio-respiratory functions as shown in Fig. 13 because of the encroaching pregnant uterus on the lung capacity.

Fig. 11 presents the same data as in Fig. 10 but on an arithlog grid in which slopes are proportional to *relative* or percentage changes rather than to *absolute* or arithmetical changes shown in Fig. 10.

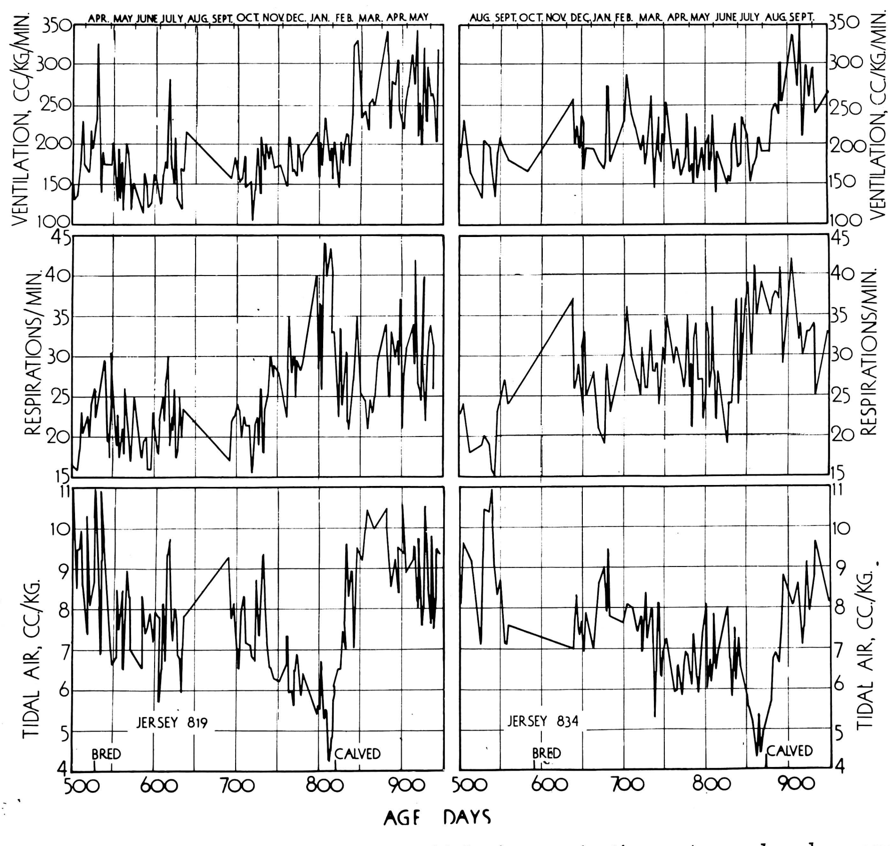

Fig. 13.—Interrelations between tidal air, respiration rate, and pulmonary ventilation rate during gestation and lactation of two Jersey heifers that calved six months apart (July and January).

TABLE 2. HEAT PRODUCTION AND CARDIORESPIRATORY FUNCTIONS DURING GROWTH OF JERSEY HEIFERS
(Values interpolated from charts of monthly observations)

Animal No:	818	819	821	822	823	825	826	827	828	829	831	833	834	835	836	837	Average
At Age Six Months																	
Body weight, lbs.	275	270	225	225	200	175	225	215	200	210	225	180	200	200	225	----	217
Heat production, Cal/day:																	
Per square meter	2200	2500	2000	2300	2250	2020	2000	2100	2100	1850	2080	2000	1800	2100	2000	----	2087
Per animal	5000	5500	4000	4500	4250	3500	4000	4000	4000	3600	4000	3600	3500	4000	4000	----	4097
Pulse per min.	----	78	----	83	82	67	67	76	76	71	79	82	79	79	78	----	76.7
Respirations per min.	32	27	35	46	36	28	32	29	30	32	32	44	32	30	28	----	32.9
Tidal air, liters	1.0	1.2	1.0	0.8	0.8	0.7	0.9	0.8	0.9	0.9	0.9	0.8	1.0	1.0	1.3	----	0.93
Ventilation rate:																	
Liters per min.	28	30	34	38	25	20	28	24	26	28	30	32	30	30	30	----	28.9
Cu. ft. per min.	0.99	1.06	1.20	1.34	0.88	0.71	0.99	0.85	0.92	0.99	1.06	1.13	1.06	1.06	1.06	----	1.02
At Age Eighteen Months (Approximate Age of Breeding)																	
Body weight, lbs.	750	670	625	600	575	510	490	600	550	640	630	575	525	580	580	650	597
Heat production, Cal/day:																	
Per square meter	1950	2000	2000	2300	2100	2550	2350	2100	1820	2200	2000	1800	1800	1875	2050	2200	2068
Per animal	7500	7500	7200	8000	7000	8000	7250	7500	6000	8000	7200	6000	5800	6500	7000	8000	7216
Pulse per min.	67	66	59	69	57	63	56	72	65	75	64	59	62	61	60	75	64.4
Respirations per min.	24	22	26	28	24	22	25	29	19	26	26	23	18	18	16	21	22.9
Tidal air, liters	2.9	2.8	2.0	2.4	2.4	2.2	1.4	2.2	2.2	2.2	2.0	2.7	2.4	2.0	2.8	2.3	2.31
Ventilation rate:																	
Liters per min.	72	60	50	66	58	48	35	62	44	58	52	62	42	38	45	48	52.5
Cu. ft. per min.	2.54	2.12	1.77	2.33	2.05	1.70	1.24	2.19	1.55	2.05	1.84	2.19	1.48	1.34	1.59	1.70	1.86

Air volumes reduced to S. T. P.

TABLE 3. HEAT PRODUCTION AND CARDIORESPIRATORY FUNCTIONS DURING THE FIRST GESTATION AND LACTATION PERIODS OF JERSEY CATTLE (Values interpolated from charts of monthly observations)

Animal No.:	818	819	821	822	823	825	826	827	828	829	831	833	834	835	836	837	Average
Values during the Ninth Month of Gestation																	
Age, months	25	26	28	27	28	25	27	30	33	29	31	28	29	29	29	30	28.4
Body weight, lbs.	1000	1020	970	910	825	770	760	950	990	1000	1060	900	880	925	880	975	926
Heat production, Cal./day:																	
Per square meter	2550	2000	1800	2000	2050	2000	2100	2500	2450	2200	2500	2450	2150	2180	2550	1900	2211
Per animal	11850	9200	8200	8750	8500	7900	8200	11250	11250	10000	12000	10500	9250	9300	11000	8750	9762
Heat increment of gestation Cal./day/animal	2280	-1410	-500	-580	-1120	50	950	1480	2400	40	2600	1110	1240	1310	930	-180	662
Pulse per min.	85	85	77	82	78	75	74	84	80	81	88	78	78	79	82	81	80.4
Respirations per min.	30	36	38	36	34	32	32	33	25	29	36	30	37	28	25	28	31.8
Tidal air, liters	2.7	2.6	2.2	2.8	2.0	2.3	2.2	2.5	3.0	2.3	2.5	2.7	2.1	2.6	2.8	2.8	2.51
Ventilation rate:																	
Liters per min.	80	92	83	86	65	70	74	78	78	68	89	80	78	74	68	80	77.8
Cu. ft. per min.	2.83	3.25	2.93	3.04	2.30	2.51	2.61	2.75	2.75	2.40	3.14	2.83	2.75	2.61	2.40	2.83	2.75
Values During the First Month Following Calving																	
Body weight, lbs.	925	925	900	825	775	650	680	850	875	875	990	825	775	840	----	950	844
Heat production, Cal./day:																	
Per square meter	2450	2000	2200	2500	1900	2600	2400	2800	2400	2700	2350	2700	2450	2000	----	2400	2390
Per animal	11200	8700	9500	10500	7600	9600	9000	12000	10250	12000	10750	11250	9800	8250	----	10500	10060
Heat increment of lactation Cal./day/animal	3020	-1210	180	1640	-320	2370	1041	1970	1930	-520	2760	2680	2280	2040	----	1160	1400
Pulse per min.	94	84	72	76	78	72	75	85	75	87	82	72	76	78	----	83	79.3
Respirations per min.	27	31	38	41	31	29	27	32	30	38	36	39	36	32	----	28	33.0
Tidal air, liters	3.0	2.7	2.5	2.6	2.0	3.2	2.9	2.8	2.8	2.4	2.6	2.5	2.5	2.7	----	3.3	2.70
Ventilation rate:																	
Liters per min.	80	80	96	102	60	90	78	90	84	92	92	96	88	86	----	95	87.3
Cu. ft. per min.	2.83	2.83	3.39	3.60	2.12	3.18	2.75	3.18	2.97	3.25	3.25	3.39	3.11	3.04	----	3.35	3.08
Values During the Month of Lactational Peak in Heat Production																	
Age, months	27	30	30	29	34	29	29	30	37	35	34	29	34	33	----	33	31.5
Month of lactation	2	2	2	2	5	4	2	1	4	5	3	1	5	4	----	3	3
Body weight, lbs.	920	850	900	790	810	680	690	850	900	890	1000	825	740	820	----	970	842
Heat production, Cal./day:																	
Per square meter	3000	2900	2600	2700	3250	2700	2550	2800	3440	3850	3600	2700	3200	3000	----	2750	3003
Per animal	13300	12000	11250	10800	13250	10200	9600	12000	15000	16600	16750	11250	12250	12250	----	12500	12024
Heat increment of lactation Cal./day/animal	4350	-910	2450	2310	3930	2860	1850	1970	5540	-5530	8970	2680	2885	4300	----	2440	2686
Pulse per min.	98	76	75	77	80	75	76	85	78	82	89	72	74	75	----	80	79.5
Respirations per min.	29	31	41	37	33	28	29	32	34	42	40	39	33	31	----	34	34.2
Tital air, liters	3.4	3.8	2.8	3.2	3.4	3.7	3.2	2.8	3.8	3.2	3.8	2.5	3.6	3.2	----	3.4	3.32
Ventilation rate:																	
Liters per min.	98	122	112	116	105	104	92	90	128	134	150	96	120	101	----	120	112.5
Cu. ft. per min.	3.46	4.31	3.96	4.10	3.71	3.67	3.25	3.18	4.52	4.73	5.30	3.39	4.24	3.57	----	4.24	3.98
Milk yield, FCM, lbs. per day, during 2nd month of lactation	30.4	39.0	33.2	25.7	32.8	29.3	17.8	43.0	23.0	43.7	32.9	26.2	30.7	22.9	----	45.1	31.7

From the relative viewpoint, parallelisms are, therefore, more significant on the arithlog grid, Fig. 11, than on arithmetic paper, Fig. 10.

Fig. 12 represents the various functions in Fig. 10 and 11 in terms of percentages of the respective values at 18 months, when most of the animals were bred. The ventilation rate is seen to reach a lactation peak of over 225 per cent of the breeding level, the tidal air 200 per cent, the heat production 190 per cent, the respiration 175 per cent, and the pulse rate 140 per cent.

E. Interrelation Between Tidal Air, Respiration Rate, and Pulmonary Ventilation Rate: Tidal air (volume of air exhaled or inhaled per minute) is the *capacity* factor in the respiratory function; respiration rate is the *intensity* factor; the product of the two, the pulmonary ventilation rate, tends to be constant. Thus, on collapsing one lung, the total tidal air may be halved and the respiration rate doubled. Fig. 13 (also Figs. 10, 11, and 12) shows, as might be expected from the encroaching pregnant uterus on the available space for lung expansion, that the tidal air does not increase as rapidly as the other cardiorespiratory functions in the late stages of gestation.

One would infer from the above general considerations (that the product of tidal air and respiration rate tends to remain constant under a given set of conditions), that the respiration rate would increase in the late stages of gestation. Other conditions, however, do not remain constant. In non-sweating or slightly sweating species, such as cattle, the respiration rate has also a temperature-regulating function; the higher the environmental temperature, the higher the respiration rate, which finally develops into panting. Hence, while gestation roughly halved the tidal air in Heifer 819 (Fig. 13), from perhaps 9 cc to 4½ cc (per kg body weight) and the respiration rate doubled, from about 20 per minute at breeding to 40 at calving time, this relation does not seem to hold for Heifer 834, perhaps because of complications associated with environmental temperature; or perhaps because of psychic factors associated with the inhaling of hot spirometer air that passed through layers of lime.

The data on pulmonary ventilation should be very useful in connection with our proposed climatic-factors studies because of the influence of environmental temperature on the ventilation rate and on water vaporization. It is at present assumed that, in man at least[13], when the oral temperature is 37° C. the temperature of the air as it is exhaled is 34 to 36° C. (depending, of course, on the environmental temperature); the water content of the exhaled air is 80 per cent of that of saturated air at 37° C., containing 32 to 37 mgm water per

[13]Newburgh, L. H., and Johnston, N. W., Physiol. Rev. *22*, 1, 1942.

liter (14 to 16 grains per cu. ft.) of exhaled air. The corresponding constants need to be obtained for cattle and then, perhaps, utilized for estimating their pulmonary moisture vaporization.

It is instructive to note that *in relation to heat production*, the pulmonary ventilation rate in these non-sweating or slightly sweating cattle is, roughly, double that in sweating man[3], as indicated by the fact that the oxygen decrement in the expired air of cattle (2 per cent) is approximately half that in man (4 per cent). The greater pulmonary ventilation rate in cattle is probably associated with their relative inability, in contrast to man's ability, to lose heat by sweating. Would sweating Indian cattle have a higher oxygen decrement more nearly like that of man?

IV. GENERAL DISCUSSION AND SUMMARY

1. Quantitative data are presented on the influence of gestation and lactation on the resting heat production, on body weight, and on the cardiorespiratory responses (pulse rate, tidal air, respiration rate, pulmonary ventilation rate) of 16 Jersey heifers with comparisons to similar heat production and body weight data on rats.

2. While it may be true that women show no increase in *basal* heat production during the lactation period, there is no question but that the *resting* peak heat production of lactation in rats with a good size litter, and in good dairy cows is, per unit surface area, nearly twice as great as during the non-lactation period at the time of breeding for the first gestation.

3. The resting cardiorespiratory responses (pulse, respiration, pulmonary ventilation, tidal air) roughly parallel the resting heat production, except that there is some tendency for the tidal air—and therefore, for the pulmonary reserve—to decline somewhat during the last third of the gestation period with a compensatory increase in respiration rate. This general statement concerning the relative changes in cardiorespiratory function during gestation and lactation is illustrated in Tables 2 and 3 and may be supplemented by the following general numerical estimate for our "typical" Jersey cow in Fig. 10.

The resting daily *total heat production* at 18 months (at breeding) is about 8000 Calories; at the lactation peak, about 13,000 Calories; at 50 months (drying up), about 10,000 Calories. *Per square meter* surface area, the resting heat production is about 2000 Calories from 6 months to the middle of the gestation period at about 25 months, when it rises to about 2400 Calories just before calving and to 3300 Calories at 2½ months after calving. There appear to be some discrepancies between the peaks of heat production and milk production, but these are within the limits of the overall variability due to individual variation and experimental error of our data. Moreover, the heat increments of lactation subsequent to the first lactation are confused by the heat increments of gestation.

The *pulmonary ventilation* is about 60 liters (2.1 cu. ft.) per minute at 18 months (breeding time), 90 liters (3.2 cu. ft.) at 50 months, and 125 liters (4.4 cu. ft.) at the lactation peak. (In resting man the average pulmonary ventilation rate is 8 to 10 liters or 0.28 to 0.35 cu. ft. per minute.)

The *tidal air* is about 2.0 liters (0.09 cu. ft.) at 20 and 50 months, and the peak lactation value is 4.0 liters (0.14 cu. ft.). (In resting man the average tidal air is about 0.5 liter or 0.02 cu. ft.)

The *pulse rate* is about 60 per minute at 20 and 50 months contrasted to 80 during the lactational peak.

The *respiration rate* varies with the environmental temperature, but it is of the order of 25 at 20 and 50 months contrasted to the lactation peak of 45.

The average *lactation increments* of all cows in terms of percentages above the breeding level at 18 months are about 114 for pulmonary ventilation, 67 for total heat production, 49 for respiration rate, 44 for tidal air, and 23 for pulse rate.

Similar average percentage values for the *gestation increment* (during the 9th month) are 39 for respiration, 36 for total heat production, 33 for pulmonary ventilation, 19 for pulse rate, and 9 for tidal air.