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GROWTH AND DEVELOPMENT

With Special Reference to Domestic Animals

LV. Resting Energy Metabolism and Ventilation Rate in Relation to Body Weight in Growing Holstein Cattle

Samuel Brody, H. H. Kibler, and A. C. Ragsdale

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COLUMBIA, MISSOURI

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BACKGROUND

A preceding report (Missouri Agric. Exp. Station Res. Bul. 335, 1941) presented data on the resting maintenance-energy cost ("resting metabolism") and ventilation rate (air inhaled or exhaled per minute) in relation to body weight in growing Jersey cattle during the first two postnatal years. This report presents similar data for Holstein cattle and compares them with the data for the Jersey cattle.

Since Res. Bul. 335 gave the background of the research, both methodologic and philosophic, including comparison with basal metabolism of man, it seems best to confine this report to the presentation of the factual material, referring the reader to Res. Bul. 335 for more extensive discussions.

ANIMALS AND DATA

Each data point in the charts represents the average of two to thirty measurements taken during a given month. The measurements were made while the animals were resting in a comfortably-lying position (Fig. 1, Res. Bul. 335) just before the morning feeding, under usual commercial-barn conditions.

The 15 animals measured are listed in Table 2.

The month of birth is given because the time of the year (and all that goes with it) influences the resting and basal maintenance cost (or "metabolism"). The scatter of the data on the charts is due to no small extent to the influence of seasonal factors. It was not possible to correct for the seasonal variations because there were not enough animals. It should be noted that temperature is only one of the factors influencing the seasonal variations, and that the available data on the influence of temperature on "basal metabolism" under rigorous laboratory conditions are inapplicable to these normally-fed and managed animals.

PREDICTION TABLE

Table 1 presents averages computed from the equation $Y = aX^b$ fitted to the data by the method of least squares, as explained in

FOREWORD

The special investigation on growth and development is a cooperative enterprise in which the departments of Animal Husbandry, Dairy Husbandry, Agricultural Chemistry, and Poultry Husbandry have each contributed a substantial part. The parts for the investigation in the beginning were inaugurated by a committee including A. C. Ragsdale, E. A. Trowbridge, H. L. Kempster, A. G. Hogan, and F. B. Mumford. Samuel Brody served as Chairman of this committee and has been chiefly responsible for the execution of the plans, interpretation of results and the preparation of the publications resulting from this enterprise.

M. F. MILLER
Director Agricultural Experiment Station

ABSTRACT

This bulletin presents charts, prediction tables in various units, and the fitted equation $Y = aX^b$ relating resting-maintenance energy cost Y, or ventilation rate Y, to body weight X, for the same 15 Holstein heifers during the first two postnatal years. These results are compared to similar data on Jersey cattle described in detail in Missouri Research Bulletin 335. Following age 6 months, the value of the exponent b in the above equation relating metabolism to weight is about 0.6 for both Jersey and Holstein heifers; which means that the differential percentage increase in resting maintenance cost is about 0.6 times as rapid as the percentage increase in body weight: increasing body weight 1% increases maintenance cost about 0.6%. The resting metabolism per unit surface area is somewhat higher in the Holstein heifers, namely about 2140 Cal./sq. meter, than in the Jersey heifers, about 2000 Cal./sq. meter/day. The value of b for the ventilation rate is 0.77: increasing body weight 1% tends to increase the ventilation rate about 0.77%.

TABLE 1. PREDICTION TABLE FOR RESTING ENERGY MAINTENANCE COST AND VENTILATION RATE IN GROWING HOLSTEIN CATTLE

Body Weight		Approximate age	Energy Maintenance Cost per 24 hours							Oxygen Consumption Per 24 hours (S.T.P.)				Ventilation Rate Per Minute (S.T.P.)				Ventilation rate	Ratio of oxygen Consumption to Ventilation Rate
			Calories			B.T.U.		Equivalent[2]	Total TDN[3]	Liters		Cu. ft.		Liters		Cu. ft.		Liters	
Kgs.	Lbs.	Mos.	Total	Kg.	Per Sq. M.[1]	Total	Per Lb.	in TDN	consumed, Lbs.	Total	Per Kg.	Total	Per Lb.	Total	Per Kg.	Total	Per Lb.	per Sq. M. per day	% $\frac{O_2 \text{ consumed}}{\text{Air, inhaled}}$
40	88.2	.4	1875	46.9	1600	7440	84	1.0	---	389	9.7	13.7	.155	14.3	.357	.51	.0058	17390	1.89
50	110.2	1.1	2254	45.1	1700	8940	81	1.2	1.4	467	9.3	16.5	.150	17.0	.340	.60	.0054	18260	1.91
75	165.3	2.7	3137	41.8	1870	12450	75	1.7	2.5	650	8.7	22.9	.139	23.3	.312	.82	.0050	19940	1.94
100	220.5	3.8	3965	39.7	2060	15730	71	2.2	3.8	822	8.2	29.0	.131	29.1	.291	1.03	.0047	21200	1.96
125	275.6	4.8	4757	38.1	2090	18880	68	2.6	4.9	986	7.9	34.8	.126	34.6	.276	1.22	.0044	22230	1.98
150[4]	330.7	6.0	5153	34.4	2100	20450	62	2.8	5.8	1068	7.1	37.7	.114	39.9	.266	1.41	.0043	23160	1.86
175	385.8	7.2	5649	32.3	2120	22420	58	3.1	6.2	1171	6.7	41.4	.107	44.9	.256	1.59	.0041	23900	1.81
200	440.9	8.2	6119	30.6	2130	24280	55	3.4	6.6	1268	6.3	44.8	.102	49.8	.249	1.76	.0040	24600	1.77
250	551.1	11.5	6990	28.0	2120	27740	50	3.9	7.4	1449	5.8	51.2	.093	59.2	.236	2.09	.0038	25810	1.70
300	661.4	14.2	7795	26.0	2170	30930	47	4.3	8.4	1616	5.4	57.1	.086	68.2	.227	2.41	.0036	26850	1.65
350	771.6	16.8	8547	24.4	2140	33910	44	4.7	10.1	1771	5.1	62.5	.081	76.9	.220	2.72	.0035	27770	1.60
400	881.8	19.6	9255	23.1	2160	36720	42	5.1	11.4	1918	4.8	67.7	.077	85.2	.213	3.01	.0034	28540	1.56
450	992.1	22.0	9929	22.1	2160	39400	40	5.5	11.8	2058	4.6	72.7	.073	93.4	.208	3.30	.0033	29300	1.53
500	1102.0	24.0	10570	21.1	2180	41940	38	5.8	12.9	2191	4.4	77.4	.070	101.3	.203	3.58	.0032	29960	1.50
550	1213.0	---	11190	20.3	----	44400	37	6.2	---	2320	4.2	81.9	.068	109.1	.198	3.85	.0032	30580	1.48
600	1323.0	---	11790	19.7	----	46780	35	6.5	---	2444	4.1	86.3	.065	116.7	.195	4.12	.0031	31170	1.45

[1] Calories per square meter were read from Fig. 5. Surface area was computed from the equation, surface area in sq. meters = 0.15 (weight in kg.)$^{0.56}$. See Mo. Res. Bul. 89, p. 10. The heat production was computed on the assumption that one liter of oxygen has a heat equivalent of 4.825 Calories. This value is probably slightly high for the younger calves taking milk and low for the older heifers. The error incurred by this assumption is well within the experimental error.

[2] Computed on the assumption that 1 lb. TDN (total digestible nutrients) is equivalent to 1814 Cal. or 1 gm. of TDN to 4 Cal.

[3] Interpolated from page 8 of Mo. Exp. Sta. Bul. 338 covering feed records for large groups (35 to 87 animals). This represents not resting energy metabolism computed from O_2 consumption but actual total TDN consumed.

[4] Computations for body weights of 150 Kg. and larger are based on equation (2), Fig. 2, and those for smaller body weights on equation (1), Fig. 2.

Res. Bul. 335. The fitted equations for the different curves are given on the charts.

Table 1 lists body weights in kilograms and pounds, age, resting-maintenance energy in Calories (kg.-Cal.) and British thermal units per day (24 hours) and per: animal, kg. body weight, square meter surface area, and lb. body weight. The table also lists the TDN (total digestible nutrient) equivalents corresponding to the resting-maintenance Calories (assuming 1 lb. TDN = 1814 Cal.) and also the observed total TDN consumed. Note that the observed TDN consumption is approximately twice the TDN equivalent of the resting maintenance cost as computed from oxygen consumption. This extra TDN above the resting maintenance level includes the energy stored in the growth process, the cost of moving about (above the *resting* maintenance cost), and the cost of TDN utilization.

The other columns in Table 1 present the oxygen consumption rates in various units, and ventilation rate. The ventilation-rate data should be of interest to barn and air-conditioning-system designers as well as to comparative physiologists.

CHARTS

Total Metabolism as Function of Body Weight.—Fig. 1 presents the basic metabolic data in terms of oxygen consumption (actually measured, left axis) and the equivalent (computed) heat and TDN (right axis) values plotted against body weight.

The heavy lines I and II represent the equation $Y = aX^b$ fitted to the data (each point represents a monthly average for one animal) by the method of least squares. The light broken standard-errors-of-estimates lines, designated by S_R, on each side of the heavy lines, include between them two-thirds of the data.

The light broken line III represents the *basal* metabolism of *mature* animals of *different species* (mice to elephants), copied here (from Res. Bul. 220) for comparative purposes.

The chart is divided logarithmically: equal spaces represent equal *percentage* (not *absolute*) differences; and a linear distribution of data indicates that it may be represented by the logarithmic equation, $Y = aX^b$, in which X is body weight, the independent variable or reference base, and Y is metabolism, the dependent variable. The meaning of the exponent *b* may be illustrated by reference to the equation of line III. The value of the exponent *b* is 0.73, meaning that the differential logarithmic or percentage increase in basal metabolism of mature animals of different species is about 0.7 times as rapid as the correspond-

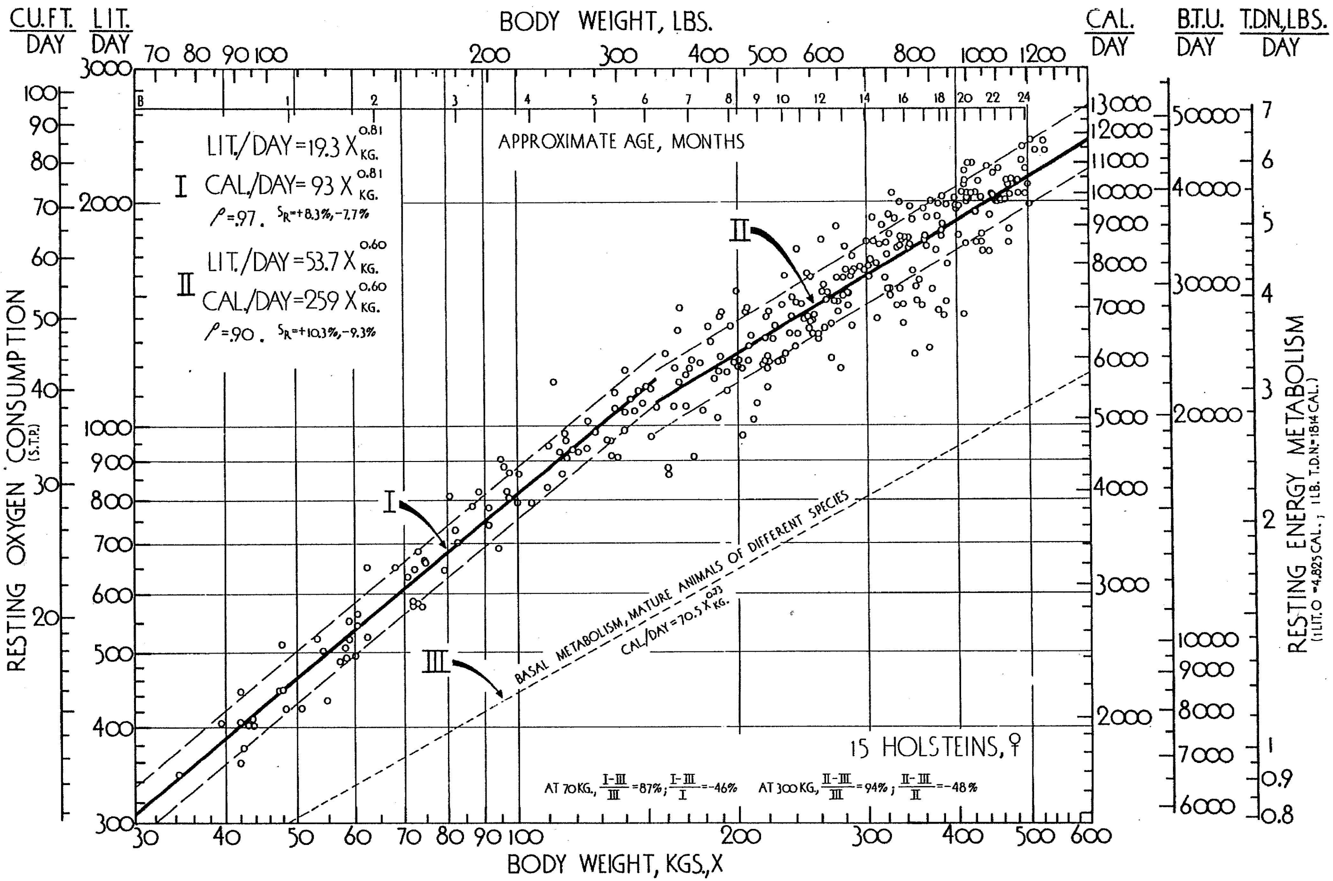

Fig. 1—Resting oxygen consumption (left axis) and heat production in terms of Cal., Btu, and TDN (right axis), plotted against body weight. The heavy line represents the equation $Y = aX^b$ with the values *a* and *b* given on the chart, as well as of $\pm S_R$, which include 2/3 of the data. The lowest dash line represents the equation $Y = 70.5X^{.73}$ for *basal* metabolism (Cal./day vs. body weight in Kg.) of *mature* animals of *different* species.

ing logarithmic or percentage increase in body weight; increasing body weight one per cent increases the basal metabolism approximately 0.7 per cent; doubling body weight does not double the metabolism but increases it only about 70 per cent (on the differential basis).

Fig. 1 shows that preceding the natural weaning age, 5 to 6 months or 300 pounds live weight, the resting maintenance cost increases with about the 0.8 power of body weight (increasing body weight 1% increases resting maintenance-energy cost about 0.8%); following this age, resting maintenance cost increases with the 0.6 power of body weight (increasing body weight 1% increases maintenance-energy cost only about 0.6%).

The data are consistently distributed as indicated by the relatively high index of correlation, rho, and especially by the low standard errors of estimate, S_R, less than 10%, which include between them two-thirds of the data.

As might be expected, the *resting* (not fasting or basal) metabolism of *growing* animals is considerably above that of *fasting* (basal) metabolism of *mature* animals. As shown at bottom of Fig. 1, the basal metabolism of mature animals of different species is about 48% below that of the resting metabolism of growing cattle, or the resting metabolism of the growing cattle is about 90% above that of the basal metabolism of mature animals of different species.

Fig. 1, then, represents the quantitative relation between "resting" energy metabolism or resting maintenance-energy cost of growing Holstein cattle and body weight; and its equations, or Table 1 based on Fig. 1, may be used for estimating the TDN that goes for maintaining resting cattle during growth, and consequently for estimating the approximate maximum TDN energy used for storage in growth under such conditions.

Metabolism per Unit Area as Function of Age and of Body Weight.—The reality of the presence of the breaks in Fig. 1 may be demonstrated by plotting the resting metabolism per unit surface area against age and against weight. As explained in Res. Bul. 335, the surface area of growing cattle varies with, approximately, the 0.6 power of body weight; Fig. 1 shows that following about 6 months the resting metabolism likewise varies with the 0.6 power of body weight. Hence the ratio $\frac{\text{resting metabolism}}{\text{surface area}}$ should be approximately constant following about 6 months or 300 lbs. live weight, the rise preceding this age or weight. Figs. 2 and 3 substantiate this expectation.

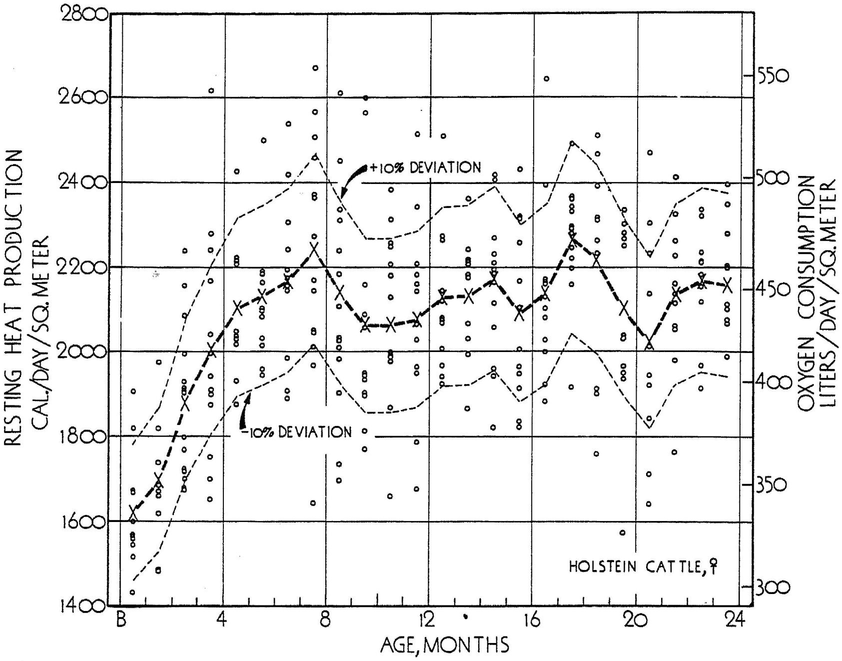

Fig. 2.—Resting heat production per square meter of surface area for the 15 Holstein heifers plotted against age.

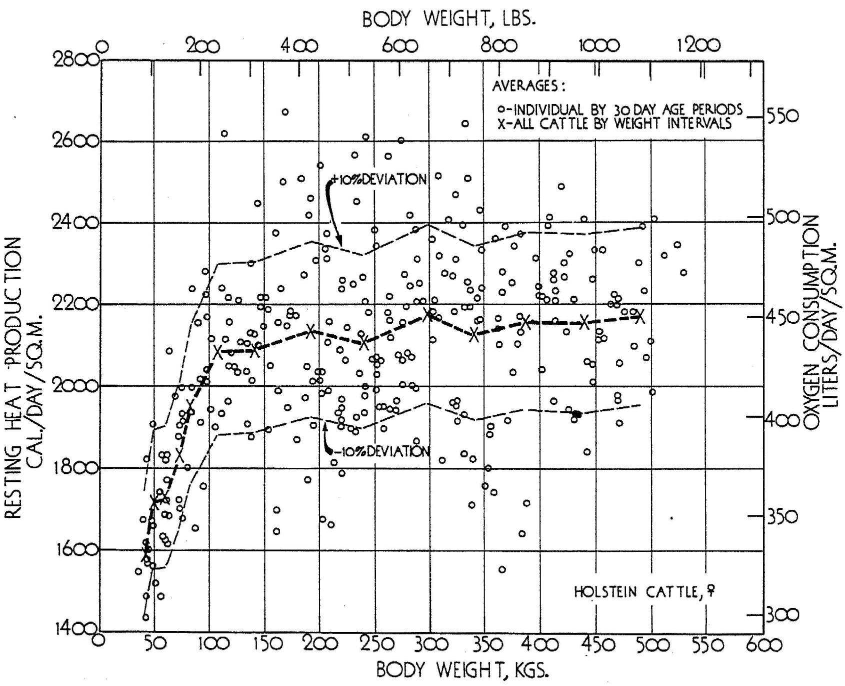

Fig. 3.—Resting heat production per square meter of surface area for the Holstein heifers plotted against body weight.

Note from Figs. 2 and 3 while the spread (variability) of the data *appears* large (because the axis of ordinates does not begin at zero), it is actually relatively small, over two-thirds of all the data fall within 10% of the average.

TABLE 2. HOLSTEIN HEIFERS INCLUDED IN FIG. 2

Herd No.	Metabolism-Measurement Period[1] Months	Age Bred Months	Birth Month
590	1st to 24th	18	Dec.
591	Birth to 24th	18	Feb.
592	Birth to 24th	19	May
593	1st to 24th	18 1/2	July
595	1 wk. to 18th	--	Nov.
596	1st to 24th	21	Nov.
597	Birth to 24th	21 3/4	Nov.
599	Birth to 24th	21	Dec.
600	1 wk. to 24th	20 1/2	Jan.
601	Birth to 24th	20 1/2	Feb.
602	1 wk. to 24th	19 1/2	March
603	1st to 24th	--	April
604	2nd to 24th	20 3/4	May
669	2nd to 24th	25 3/4	Dec.
670	2 wk. to 24th	--	Jan.

[1]Periods included in general oxygen-consumption chart, Fig. 2, and Ventilation chart, Fig. 3.

Ventilation Rate.—Fig. 4 shows that the variability of the ventilation rate data (volume air inhaled or exhaled per minute) is about twice as great as that of the oxygen consumption rate data. This is expected because the ventilation rate is regulated not only for supplying oxygen to and removing carbon dioxide from the animal but in (non-sweating) cattle also for cooling purposes (as by panting). Moreover, the oxygen percentage removed from the inhaled air varies with age and other circumstances. For this reason of greater variability of ventilation rate, it was not practicable to analyze the general ventilation curve (Fig. 4) into finer components or segments as was done for the metabolism curve (Fig. 1).

Fig. 4 shows that the general trend of the ventilation rate in growing Holstein heifers tends to vary with the 0.77 power of body weight: increasing body weight 1% tends to increase ventilation rate about 0.77%.

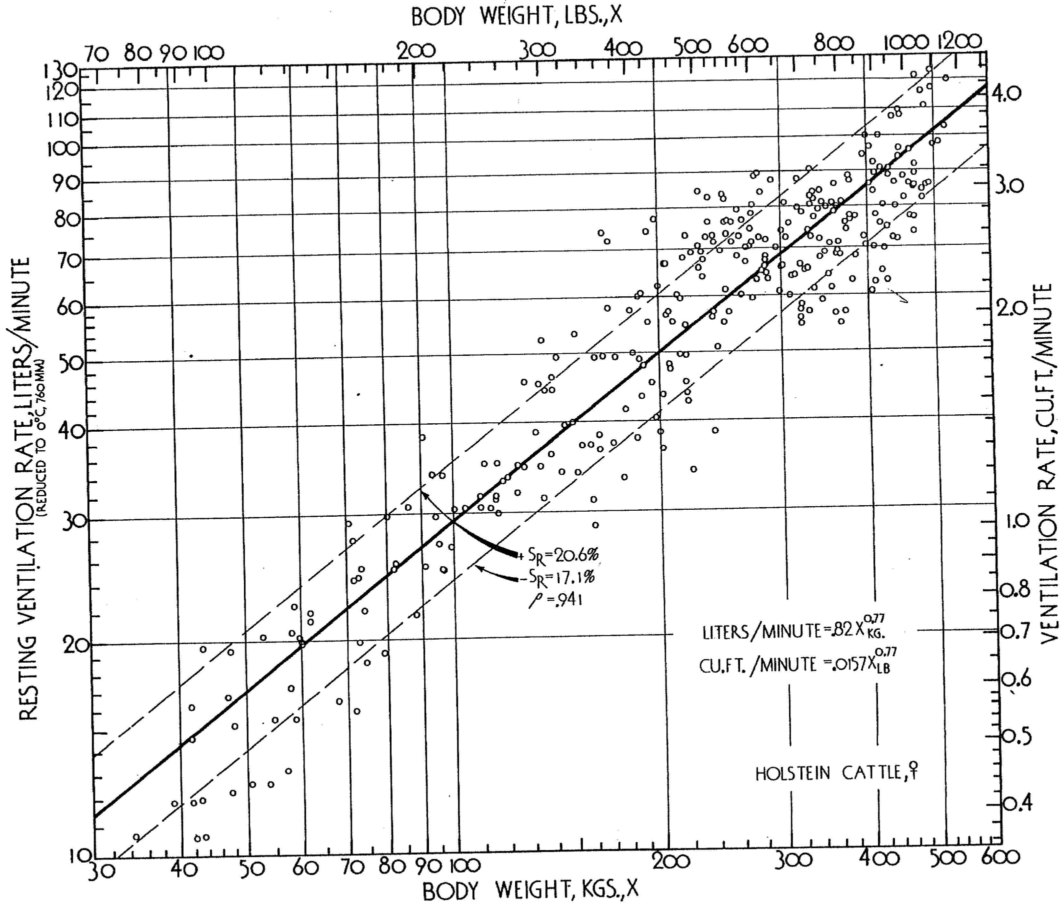

Fig. 4.—Ventilation rate (volume of air expired or inspired per minute) plotted against body weight. As in Fig. 1 the heavy line represents the fitted equation $Y = aX^b$, the dash lines, the standard error of estimate, S_R.

COMPARING THE HOLSTEIN AND JERSEY METABOLISM DATA

Fig. 5 compares the present Holstein metabolic and ventilation rate data with the Jersey data presented in Res. Bul. 335. Following age about six months the resting metabolism of the Holstein heifers is, on the average, 2140 Cal./Sq. meter/day; of the Jersey heifers, 2000 Cal./Sq. meter/day. While these breed differences are relatively slight, they are significant statistically as indicated in Table 3.

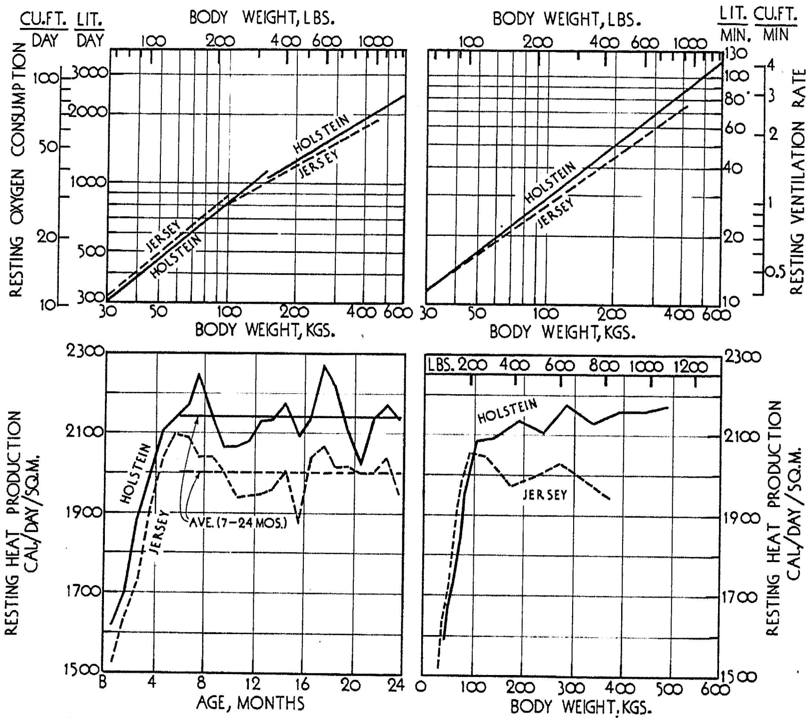

Fig. 5.—Comparison of the Holstein and Jersey data for given ages and body weights.

It is not possible to explain with assurance these breed differences. It may, however, be suggested that the higher metabolism per unit surface area of the Holsteins *at given ages* (lower left chart, Fig. 5) may be due to their more rapid growth rate. There is considerable evidence indicating that the heat production in-

TABLE 3A. MONTHLY BREED COMPARISON OF RESTING HEAT PRODUCTION PER SQUARE METER

Age Mos.	Average Cal./Sq.M./day Holstein (H)	Jersey (J)	Difference of means H.-J. (d)	Standard error of difference of means (S_d)	Degrees of freedom	Ratio $\frac{d}{S_d}$
7	2171	2088	+ 83	119	25	0.70
8	2245	2041	+204	83	27	2.45*
9	2142	2043	+ 99	76	27	1.30
10	2066	2004	+ 62	79	27	.78
11	2066	1937	+129	71	30	1.81
12	2079	1952	+127	89	28	1.43
13	2132	1947	+185	61	28	3.03*
14	2135	1964	+171	56	27	3.05*
15	2175	2058	+117	68	29	1.72
16	2092	1879	+213	93	27	2.29*
17	2139	2042	+ 97	67	29	1.44
18	2272	2074	+198	70	28	2.84*
19	2219	2016	+203	83	24	2.45*
20	2105	2019	+ 86	73	25	1.18
21	2023	2001	+ 22	106	22	.21
22	2138	2001	+137	97	23	1.41
23	2170	2039	+131	78	22	1.68
24	2160	1949	+211	62	23	3.40*

*Significance of breed differences (less than 5 chances out of 100 that differences are due to chance) are established for ages on starred lines by means of the t-test (See G. W. Snedecor, Statistical Methods, p. 71, Collegiate Press, Ames, Iowa, 1937).

TABLE 3B. ANALYSIS OF VARIANCE OF HEAT PRODUCTION PER SQ. METER WITH AGE WITHIN BREEDS

Source of variation	Degrees of freedom	Sum of squares	Mean square	F ratio
		Holstein		
Total	226	9800732		
Between ages	17	860821	50637	1.18
Between cows of same age	209	8939911	42775	
		Jersey		
Total	279	11114557		
Between ages	17	810555	47680	1.21
Between cows of same age	262	10304002	39328	

Following 6 months, heat production per square meter does not differ significantly between cows of different ages for either breed. In other words, following 6 months the resting metabolism per square meter is practically constant, and may be expressed as average of entire period 7 to 24 months as indicated by fine lines in Fig. 5.

TABLE 3C. ANALYSIS OF VARIANCE OF BREED DIFFERENCES IN HEAT PRODUCTION PER SQ. METER
(7-24 Mos.)

Source of variation	Degrees of freedom	Sum of squares	Mean square	F ratio
Total	506	23333150		
Breed groups	1	2417861	2417861	58**
Within breed groups	505	20915289	41416	

**There is less than 1 chance in 100 that the differences found between breeds could have arisen by chance. The tests for significance were made by means of Snedecor's table of F ratios, p. 174, 1.c.

creases with increasing growth rate,[1] or that there is an "organizational expense" to growth.[2]

When plotted against *body weight*, on the other hand, the metabolism per unit surface area and per animal appears to be greater in the Jerseys prior to about 100 kg. body weight (lower-right and upper-left curves, Fig. 5). This may be due to the fact that at a given body weight the Jersey is physiologically older than the Holstein, and, as indicated in the charts, the metabolism per unit surface area (and per animal) rises with increasing age up to about six months, or up to about 100 kg. body weight.

The higher Holstein ventilation rate at given body weights (upper-right curve, Fig. 5) may perhaps be explained by the higher Holstein heat production (lower-right curve, Fig. 5): ventilation rate is adjusted not only to the need for oxygen but also to the need for heat dissipation since ventilation is an important method of heat dissipation in cattle and other non-sweating animals.

[1]Du Bois, E. F., Clinical Calorimetry, Arch. Int. Med., 17, 887, 1916. Coleman, W., & Du Bois, E. G., Id., 15, 887, 1915. Riddle, O., Nussman, T. C., & Benedict, F. G., Metabolism during growth in a common pigeon, Am. J. Physiol., 101, 251, 1932. Kibler, H. H., & Brody, S., Metabolism and growth rate of r-ts, J. Nutrition, 24, Nov., 1942.

[2]Terroine, E., & Wurmser, R., Le energie de croissouce, Bull. Soc. Chim. Biol., 4, 519, 1922. Tyler, A., On the energetics of differentiation. Pub. Staz. Zool. Napoli, 13, 155, 1933; also in Biol. Bull., 68, 451, 1935.

SUMMARY

A preceding report (Missouri Agr. Exp. Station Res. Bul. 335) presented data on the resting maintenance energy cost ("resting metabolism") and ventilation rate (air inhaled or exhaled per minute) in relation to body weight in growing Jersey cattle during the first two postnatal years. This report presents similar data for Holstein cattle and compares them with the data for the Jersey cattle.

The methods, conclusions, and results of the study on Holstein cattle are identical with those for Jersey cattle. However, following the age of about six months, the resting metabolism of Holstein heifers is about 2140 Cal./Sq. meter/day whereas that of Jersey heifers is about 2000 Cal./Sq. meter/day. The metabolism per square meter is lower preceding the age of six months in both breeds, beginning with about 1300 Cal./Sq. meter/day shortly after birth and attaining the stabilized level of about 2000 Cal. in Jerseys and 2140 Cal. in Holsteins following the age of about six months.