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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

LII. EFFECTS ON CONSTANT ENVIRONMENTAL TEMPERATURES OF 50° AND 80° F ON THE GROWTH RESPONSES OF HOLSTEIN, BROWN SWISS, AND JERSEY CALVES

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SUMMARY

A twelve month investigation was conducted to determine the influence of constant environmental temperatures of 50° F and 80° F on physical growth responses (body weight, wither height, and chest girth) of Holstein, Brown Swiss, and Jersey calves from a few weeks of age to approximately one year.

The physical measurements indicate that both the Holsteins' and Jerseys' growth was depressed at the high (80° F) environmental temperature. The 50° F Holsteins averaged approximately 80 pounds heavier at the conclusion of the experiment than the 80° F-reared animals. The Brown Swiss did as well at 80° F as at 50° F.

Remarkable temperature-age effects on weight gains were observed in the various breeds. For example, the 50° F Holsteins and Jerseys had higher rates of gain than the 80° F animals until approximately eight months of age. Toward the end of the experiment, the 80° F animals were making greater gains. Apparently temperature influenced or altered the normal age trend in daily gain, or the 80° F animals attained a level of acclimation after eight months of age.

The relative breed differences in heat tolerance previously demonstrated in mature Holstin, Brown Swiss, and Jersey cattle were also demonstrated in these young growing dairy calves. These observations re-emphasize the fact that physical size is only one of the characteristics that play a role in adaptation and acclimation to high environmental temperatures.

Body weight, chest girth, and wither height data collected under controlled environmental conditions are of particular importance as growth standards and for predictions of growth.

ACKNOWLEDGMENTS

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Acknowledgments are due to M. M. Jones and R. G. Yeck for cooperation on the engineering phase of the Climatic Laboratory portion of the work; to Dr. Homer E. Dale for veterinary care; to Harry Ball and Leonard Ayres for care and feeding of the animals; to Samuel Barrett for engineering aid; to James Kennedy for making the growth measurements; to Desta Baket and Joan F. Jones for assistance in data analysis; and to Barbara Beahringer for preparation of the manuscript.

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The general objectives of this experiment were: (1) to determine the effects of environmental temperatures (50° and,80° F) on growth of dairy calves; (2) to provide basic information on young calves, "the dairyman's future herd"; (3) to provide information, derived from physical and physiological data, that will be helpful in the selection of individuals or the breed best suited for the varied and extreme climates found throughout the world; (4) to evaluate the effects of environmental temperature on calves' growth and reproductive development as well as milk-producing ability at maturity.

This investigation of growth of dairy calves at 50° and 80° F follows a similar study on beef calves (Shorthorn, Santa Gertrudis, and Brahmans). Environmental conditions were identical for both groups and, consequently, will permit eventual physiological comparison of the six breeds.

More specifically, this bulletin is a report on the physical growth responses of the Holstein, Brown Swiss, and Jersey calves at 50° and 80° F environmental temperatures. The responses described are: body weight, heart girth, and wither height. Surface area measurements will be published with the beef calf data in a bulletin of this series.

LITERATURE

One of man's oldest agricultural occupations is the rearing of cattle, swine, and sheep. Throughout history, however, little has been learned about the direct effects of climate upon the growth of these domestic animals.

This investigation describes the effects of two environmental temperatures on the physical growth responses of three breeds of dairy calves. It considers changes in mass and shape of the animals due to an integrated function of the body cells described as growth or the "creative principle" of the body (Smith, 1932). Associated with growth is an increase in mass and change in form . . . a gradual increase in cell differentiation followed by an extended subsidence in this activity. Data collected in this study which reflect such developmental modifications are measurements of body weight, heart girth, and wither height. This information will provide valuable descriptions of growth phenomena under controlled environmental conditions and facilitate understanding of the related processes.

Several investigators have reported that relatively high temperatures will result in adverse effects on the weight gains of cattle (Ragsdale, *et al.,* 1957, Bonsma, 1947), swine (Heitman, *et al.,* 1958), and other domestic and laboratory animals. A study by Hancock and Payne, for example, demonstrated that European-type cattle raised in he Fiji Islands were depressed in weight, wither height, and chest girth in some stages of growth when compared with their twins raised in New Zealand. Since the quality of feed was controlled, the differences in growth responses were assumed to reflect differences in temperature and humidity between the two locations. Hancock and Payne stated: "European-type cattle are usually stunted in the tropics, growth is slow, sexual maturity is delayed, and meat and milk production are consequently poor."

METHODS

Design of Experiment. The experiment was conducted under controlled environmental conditions in the climatic laboratory. This laboratory consists of two independently controlled chambers, each arranged to contain three calves in each of three pens. Chamber I was maintained at a constant temperature of 50° F with 62 percent relative humidity; Chamber II was maintained at a constant temperature of 80° F with approximately 54 percent relative humidity. Illumination was provided by one 40-watt incandescent bulb which was on at all times and six 200-watt incandescent bulbs which were on between 6 a.m. and 6 p.m. in each chamber. Air velocity was approximately 50 feet per minute. 50° F is "near" optimum for growth, whereas 80° F, though not severely stress-provoking, will cause European animals to make various physiological adjustments to maintain a constant body temperature.

Experimental Animals. Calves in this experiment represented two relatively large dairy breeds, Brown Swiss and Holstein, and a smaller dairy breed, Jersey. Three calves of each breed were placed in each chamber of the climatic laboratory at approximately one month of age and were kept in the chamber until the termination of the experiment, when they were approximately 13 months of age. Vital statistics of the calves are provided in Table 1.

Feeding Program. The feeding program was similar to that outlined by Herman (1937). Upon being placed in the laboratory on October 1, 1956, and until February 1, 1957, the calves were maintained on a calf starter ration. This ration contained 72% TDN content, 15.6% digestible protein, and 18.7% crude protin. On February 1, 1957, the rations were changed to an older calf and heifer mix which had a TDN content of 79.5%, digestible protein content of 11%, and

TABLE 1--VITAL STATISTICS OF CALVES

Breed	Herd No.	Birth Date 1956	At Beginning of Experiment (Sept. 27, 1956) Age Mos.	Age Days	Average Age Days	Body Weight lbs.
		Chamber I (East) - 50°F				
Brown Swiss	17	Aug. 16	1	11		107.0
	18	Aug. 26	1	1		104.5
	23	Sept. 9	0	18		95.7
					31.3	
Holstein	845	Sept. 1	0	26		122.0
	847	Sept. 5	0	22		94.5
	848	Sept. 13	0	14		102.0
					20.7	
Jersey	633	Sept. 8	0	19		59.0
	635	Aug. 23	1	4		43.0
	636	Sept. 23	0	4		48.0
					20.0	
		Chamber II (West) - 80°F				
Brown Swiss	19	Aug. 27	1	0		106.7
	20	Aug. 31	0	27		100.0
	21	Sept. 3	0	24		104.0
					27.3	
Holstein	846	Sept. 1	0	26		112.0
	849	Sept. 14	0	13		106.0
	850	Sept. 16	0	11		94.5
					16.7	
Jersey	634	Sept. 12	0	15		43.0
	637	Sept. 23	0	4		57.0
	631	Aug. 28	0	30		60.0
					16.3	

crude protein content of 13.5%. (See Appendix 1 and subsequent bulletins for more details of the rations and feeding program). Average quality of Alfalfa hay was available *ad libitum.* Water was available from drinking cups at all times.

Physical Measurements. Throughout the growth study, body weight measurements were made twice weekly. Weights were taken before the morning feeding. Wither height and chest girth measures were taken weekly with the usual wither height apparatus and tape measure. Photographs of the animals were taken monthly at a distance of 12 feet and 10 inches.

Physiological Measurements. The physiological reactions measured and the frequency of the measurements are given in Table 2. All of these physiological reactions are related to or interrelated with growth and reflect the growth responses of the calves. However, in this publication, discussion will be confined to the measurements of body weight, height at withers, and chest girth, and to the numerical relationships among these measurements during increases in age and size. Other physiological measurements listed in Table 2, such as metabolism,

TABLE 2--ANIMAL REACTIONS MEASURED

Measurement	Approximate Frequency per Calf
Body Weight	Twice weekly
Wither Height and Chest Girth	Bi-monthly
Surface area	Monthly
*Water Consumption	Continuously
*Feed Consumption	Daily
*Pulse Rate	Daily
*Respiration Rate	Daily
*Rectal Temperature	Daily
*Metabolism, lung vaporization, and Tidal air volumes	Twice weekly
*Total Vaporization Rates	Twice weekly
*Blood Volume and total and extra-cellular body water	Every five weeks
*Thyroid in vivo counts	Daily for five weeks following injection
*Blood Glutathione	Every six weeks
*Animal Surface Temperature	Weekly
*Hair Growth and Density	Monthly
*Ovarian Activity	Three times weekly
*Physical Activity	Continuously

* To be published in subsequent bulletins by members of this project.

vaporization rate, blood volume, thyroid activity, feed and water consumption, and surface temperature will be presented in subsequent bulletins.

Computation Methods. Methods of calculating growth rate and derivation of equations are given in detail in Brody's *Bioenergetics and Growth* and by Ragsdale (Ragsdale, *et al.,* 1957). Briefly, we have represented growth in weight in three recognized ways: (1) *cumulative,* or course of growth, or the total weight at a given age (Figure 6); (2) *absolute* gain in the given magnitude per unit time (Figure 8); or (3) *instantaneous* percentage rate of growth (Figure 7). All these forms of representation may be made in conventional mathematical terminology.

The absolute gain in the observed weight difference, W_2-W_1, for the corresponding time difference $t_2 - t_1$, may be represented by the equation:

$$\text{Average absolute growth rate} = \frac{W_2-W_1}{t_2-t_1} = \frac{\text{larger weight less smaller weight.}}{\text{larger time less smaller time}}$$

The instantaneous rate of growth can be obtained by the equation:

$$k = \frac{\ln W_2 - \ln W_1}{t_2-t_1}$$

In other words, the instantaneous relative growth rate, k, is the difference between the natural logarithms of weights W_2 and W_1 divided by the time interval t_2-t_1. Thus, the practically impossible task of measuring the instantaneous growth rate in the laboratory is made possible by a mathematical device (Brody, 1945).

The parabola $Y = aX^b$ was employed in predicting weight from chest girth or wither height measurements. In this equation the independent variable, X, represents the measurements of chest girth or winter height, whereas the dependent variable, Y, stands for the body weight; *a* is a constant and *b* is the slope. If the data yield a straight-line distribution when plotted on log-log paper, the equation represents the data, and can be fitted to the data logarithmically by the method of least squares.

The modified exponential equation $W = A - Be^{kt}$ was used in predicting the mature weight of the calves. The equation is fitted to the data graphically (Brody, 1945). (A–W) is plotted against age, t, on arithlog paper. A straight line results if the proper value of A is chosen and if the equation represents the data. Several values of A were chosen, and A–W was plotted. There was an upward curvature for a high value of A, a downward curvature for a low value of A, and linear distribution for the correct value of A. The value of k is determined by measuring the resultant slope on the arithlog paper. B is the intercept of the curve on the arithlog plot; that is, the value of (A–W) when t = O. B may, of course, be evaluated algebraically;

$$A - W = Be^{kt}$$

$$B = \frac{A-W}{e^{kt}} = (A-W)e^{-kt}$$

RESULTS

The data are presented qualitatively by comparing photographs of the animals at different ages; semi-quantitatively by comparing the slopes of the age curves of growth; and quantitatively and statistically by fitting the relative growth equation, that is, the parabola $Y = aX^b$, to the data. Figures 1, 2, and 3 are photographs of the animals which show the individual growth responses within the three breeds. Figure 4 summarizes the pictorial record of the breeds' responses to the 50° F and 80° F environmental temperatures. The photographs record the depressing effect of 80° F, compared to 50° F, on the Holsteins' and Jerseys' growth. Such striking differences were not apparent in the 80°F Brown Swiss which actually weighed more during growth than the 50° F animals. The pictorial records also indicate that the hair coat color of the 50° F Jerseys and Brown Swiss is darker than that of the 80° F animals.

Rectal Temperature. The rectal temperatures in Figure 5 reflect the inability of the animals to maintain a state of homeothermy. The greatest 80° F–50° F rectal temperature differences are evident in the Holsteins which were most affected at 80° F. There was somewhat less difference between the two temperature groups of Jerseys and essentially no difference for the Brown Swiss. The illustrated elevated rectal temperatures are consistent with depressions in growth

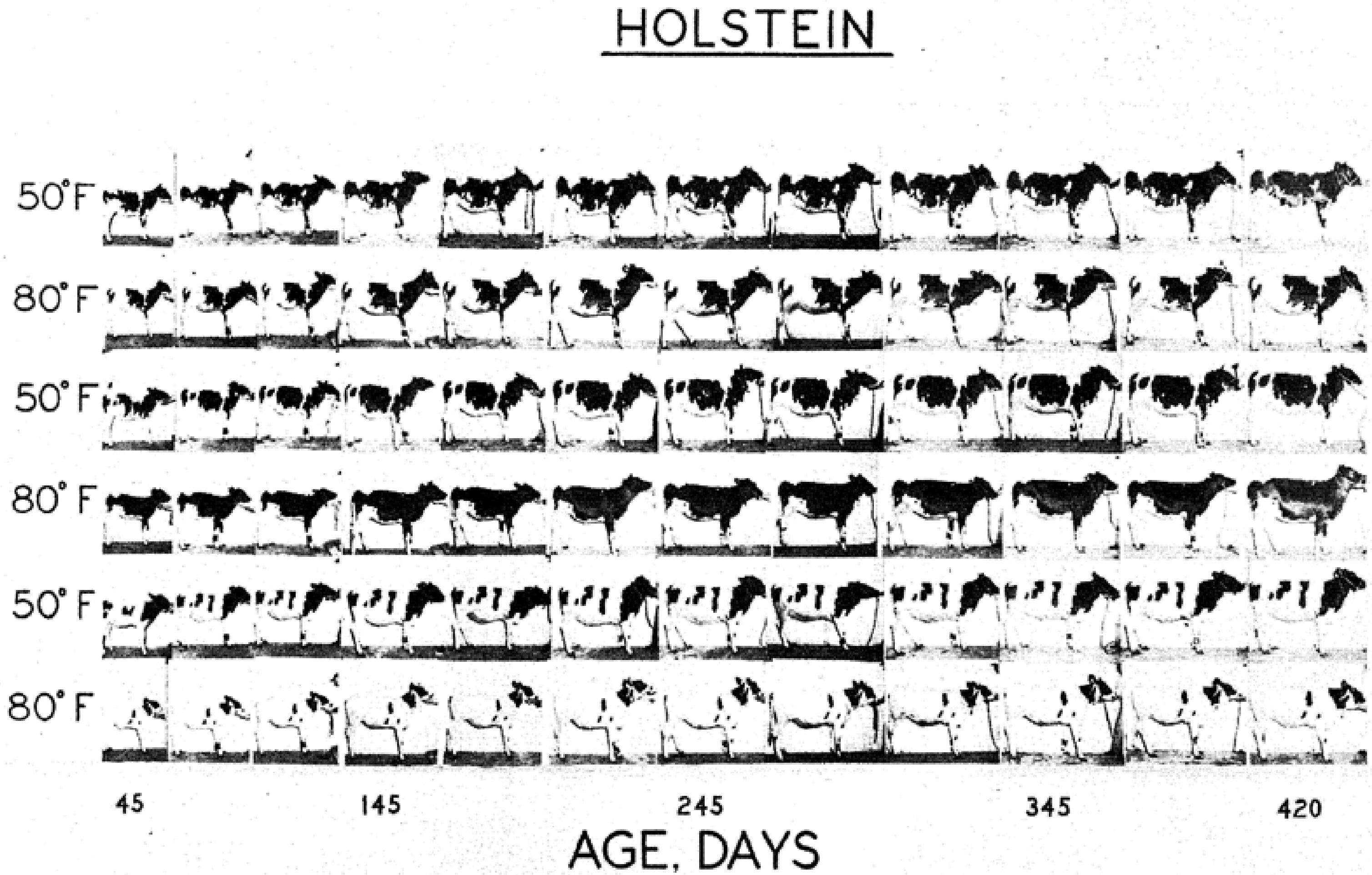

Fig. 1—The growth of the 80° F Holstein calves was depressed significantly. The 50° animals averaged approximately 90 pounds heavier than those raised at 80° F at 420 days of age. Photographs were taken at one month intervals.

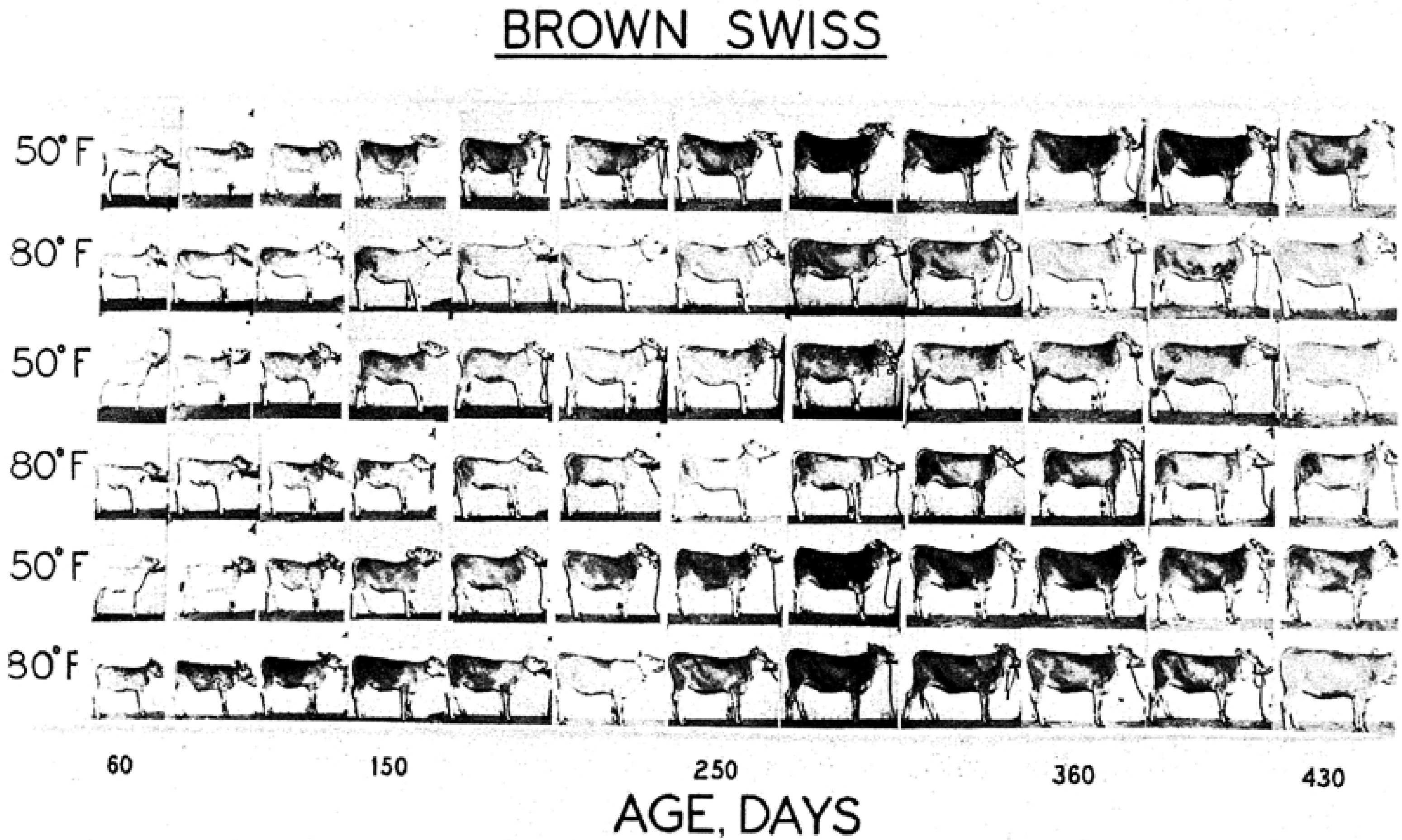

Fig. 2—The Brown Swiss raised at 80° F weighed as much as those raised at 50° F. Photographs were taken at aproximately one month intervals.

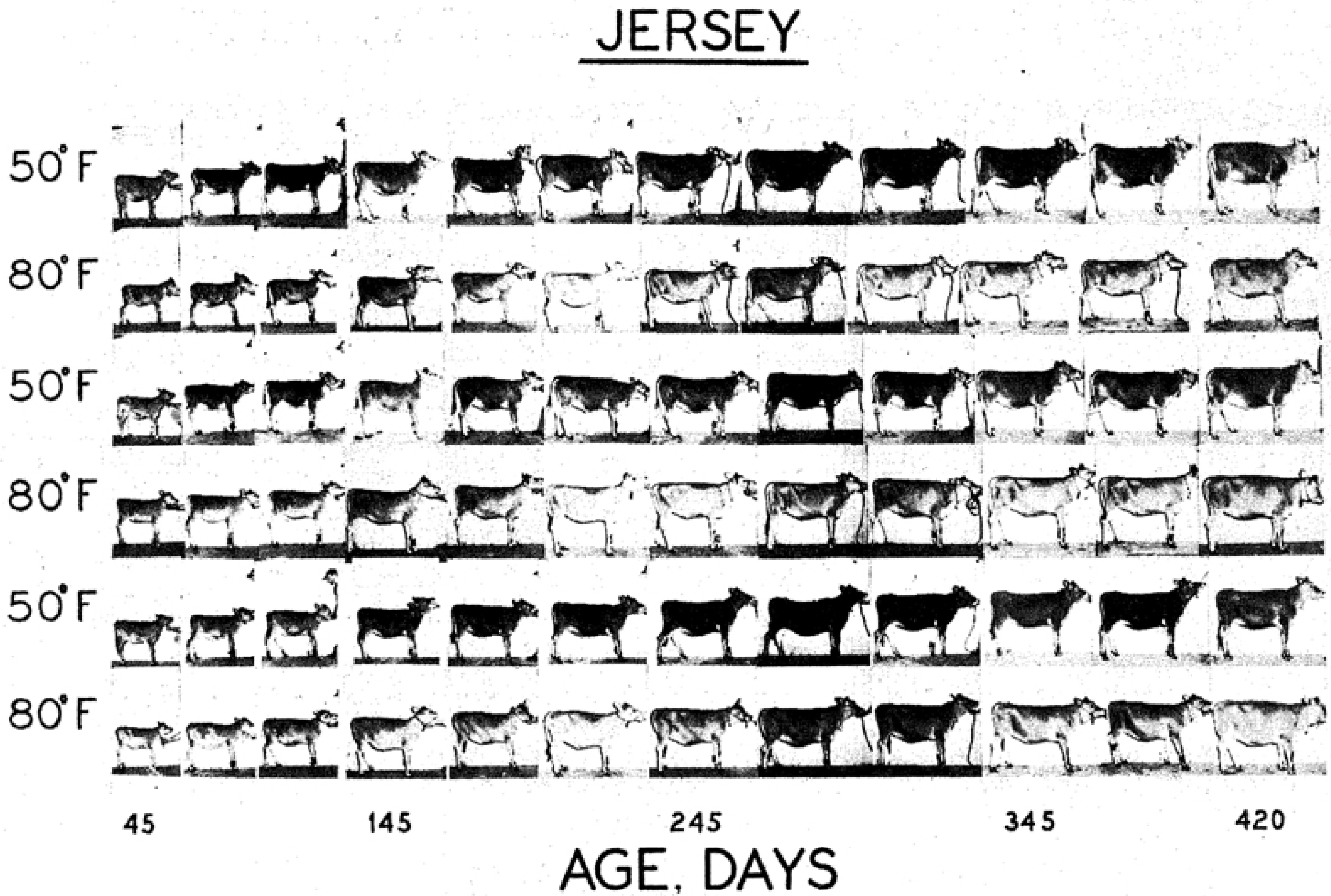

Fig. 3—Growth of 80° F Jerseys was significantly depressed, although not to the extent of that of the Holsteins. Photographs were taken at approximately one month intervals. The striking differences in hair color should be observed. This characteristic will be discussed in a subsequent bulletin.

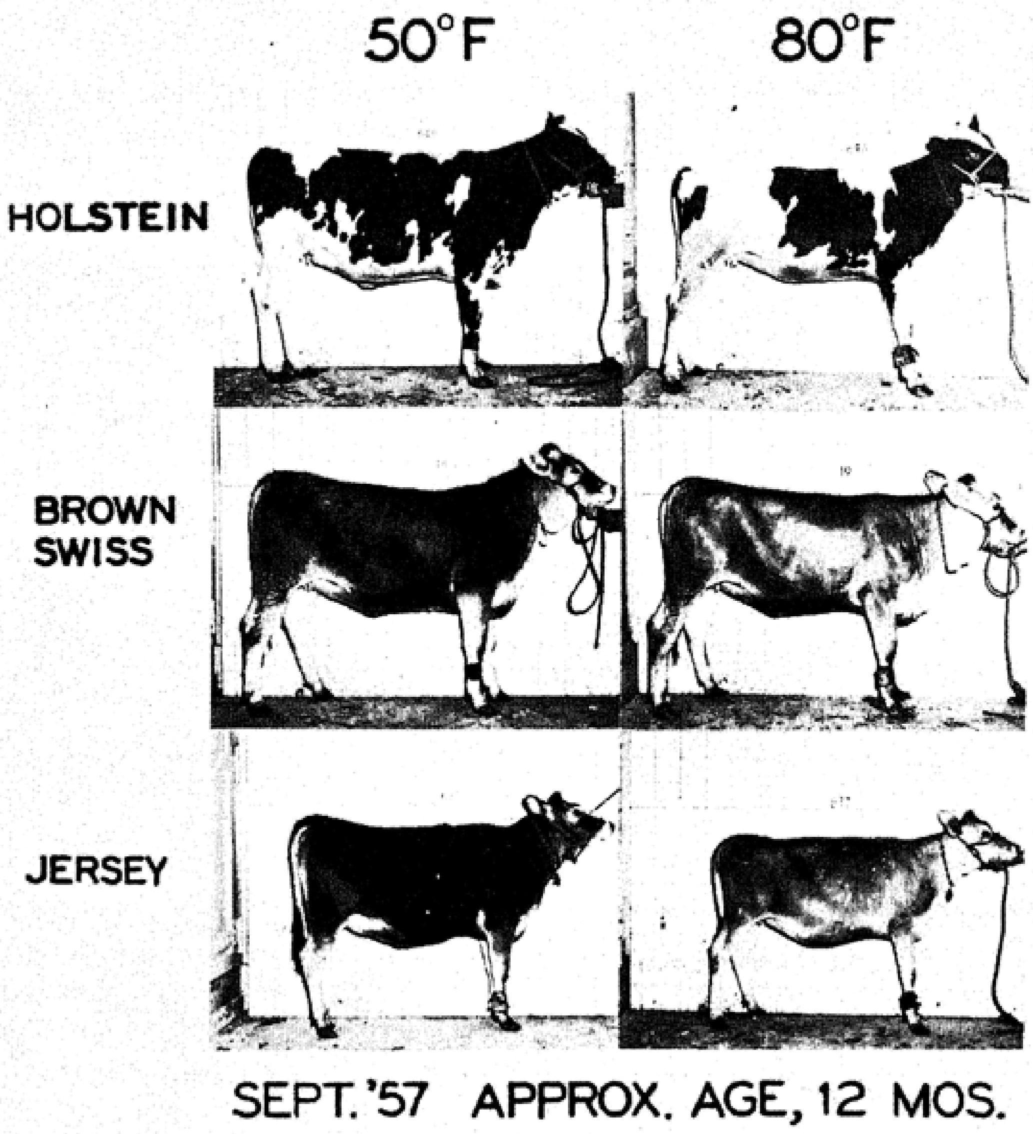

Fig. 4—Representatives of the three breeds, raised at 50° F and 80° F. The difference in the growth of the 50° F and 80° F Holsteins is obviously greater than that in the Brown Swiss or Jerseys. Differences in hair coat and density also may be observed. Details of these characteristics will be reported in subsequent bulletins.

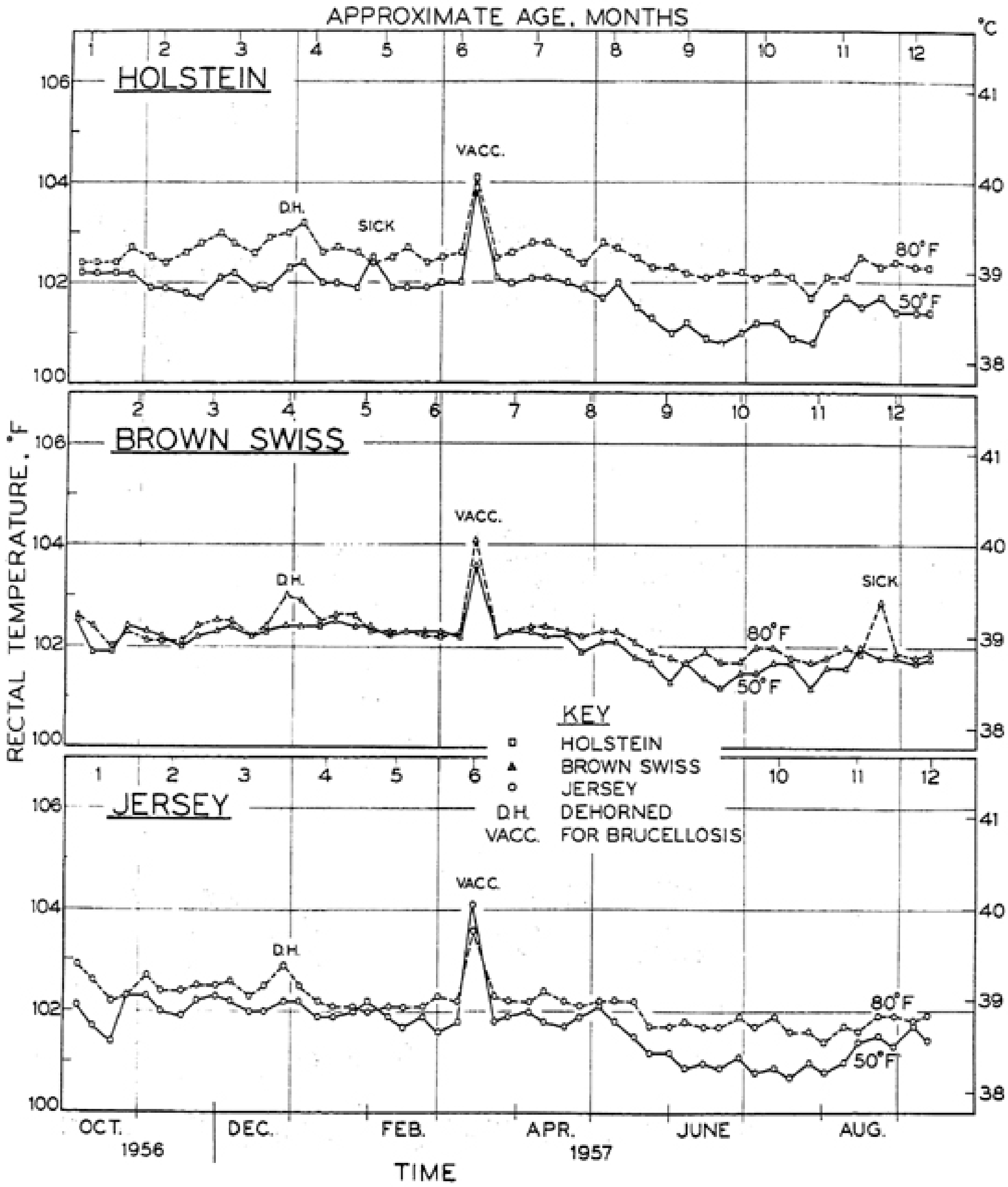

Fig. 5—AVERAGE WEEKLY RECTAL TEMPERATURE DURING GROWTH AT 50° F AND 80° F. These data represent daily measures, 7:00-8:00 a.m., taken by H. E. Dale. Other rectal temperature data on these animals during growth were collected at approximately 2:00 p.m. (time of metabolism measurements). They will be reported by H. H. Kibler.

induced by high environmental temperatures. The difficulty in maintaining homeothermy is closed associated with lower rates of growth.

Weight, Chest Girth, Height at Withers. Figure 6 summarizes the effect of constant environmental temperatures of 50° and 80° F on the average weight, chest girth, and height at withers for the various breeds. The values of measurement are also shown in Appendices 2, 3, and 4 and a table showing results of a variance analysis of age and weight is presented in Appendix 5.

Chest Girth vs. Age. Figure 6 emphasizes the similarities of chest girth and body weight measurements, both of which vary as a function of temperature and increase with age. Each chest girth datum point represents the bi-monthly average measurement for the 3 cows of each breed. At both temperatures, chest girth was greatest for the Holsteins, intermediate for the Brown Swiss, and smallest for the Jerseys. On the monthly average, throughout growth, the 50° F Holsteins were approximately 2.70 cm. greater than the 80° F Holsteins in chest girth; the 50° F Jerseys were approximately 5.16 cm. larger; the Brown Swiss at 80° F, on the other hand, were about 3.36 cm. greater.

Height at Withers vs. Age. Each wither height datum point represents the bimonthly average measurement for the 3 cows of each breed. There were relatively inconsequential differences in wither height, although the differences which did occur were consistent. Throughout the growth curve, the 50° F Holsteins surpassed the 80° F group by approximately 2.0 cm. in absolute height, but there was essentially no difference between the two Jersey groups. During growth, the 80°F Brown Swiss exceeded the 50° F Brown Swiss by approximately 2.9 cm. in wither height.

Weight vs. Age. The average weight per month for each breed was derived from weekly measurements of the animals. The data from the three members of each breed were pooled. In agreement with the photographs, weight data generally indicate that the Holsteins, in particular, and also the Jerseys, made greater gains at 50° F than at 80° F throughout the study. The Brown Swiss gained as much or more at 80° F during the 12-month period. Weight and age differences due to temperature were statistically significant at the 0.01 level of probability. On the average, the 50° F Holsteins outweighed the 80° F Holsteins throughout growth. At the end of the experiment, the 50° F Holsteins were approximately 76 pounds heavier than the 80° F Holsteins. The 50° F Jerseys were generally heavier than the 80° F group by approximately 20 pounds until the twelfth month of age. At this time the 80° F Jerseys were maintaining their earlier high rate of growth. At the conclusion of the experiment, the 50° F Brown Swiss were approximately 18 pounds lighter than the 80° F group. A temperature comparison of the differences in gains of the three breeds for the period from three to 10 months of age is presented in Table 3a. Table 3b indicates that the 80° F Holsteins required 1½ months longer than the 50° F Holsteins to reach the

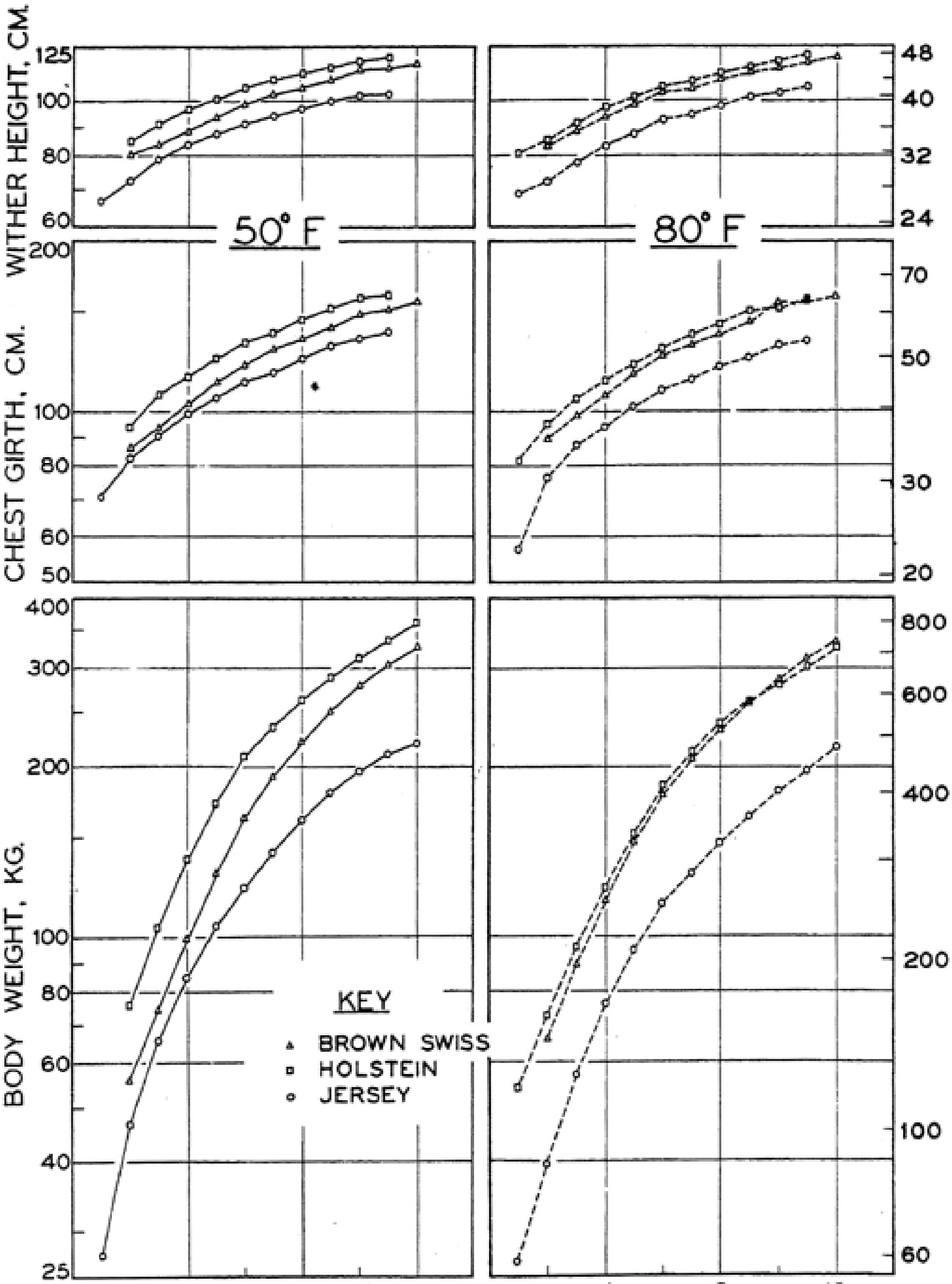

Fig. 6—AGE CURVES IN BODY WEIGHT, CHEST GIRTH, AND HEIGHT AT WITHERS OF HOLSTEINS, BROWN SWISS, AND JERSEYS AT 50° F AND 80° F. These slopes are shown on semi-log paper to represent equal relative or percentage changes.

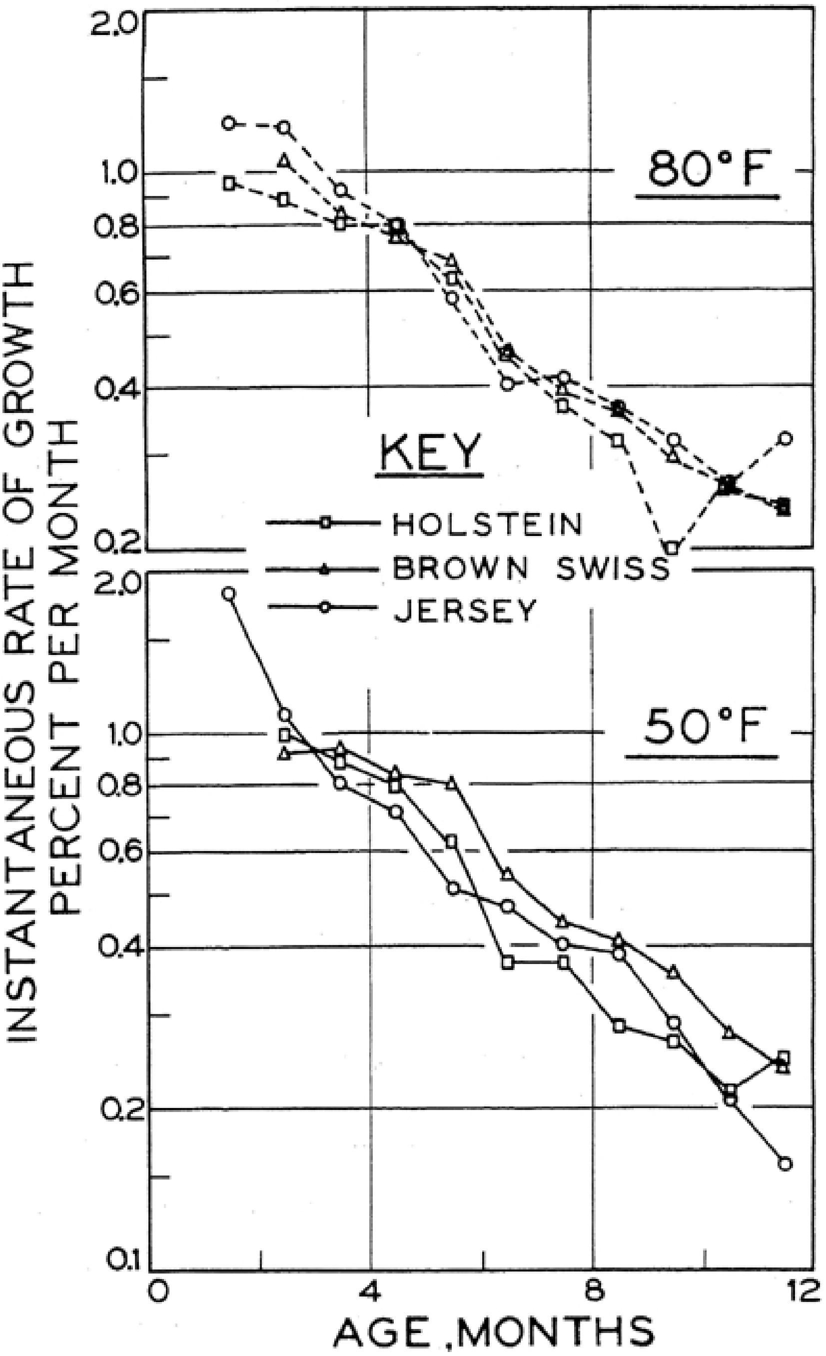

Fig. 7—INSTANTANEOUS PERCENTAGE RATE OF GROWTH OF HOLSTEIN, BROWN SWISS, AND JERSEY HEIFERS RAISED AT 80° F AND 50° F.

TABLE 3a--WEIGHT GAIN COMPARISONS

	50°F			80°F		
	Holstein	Brown Swiss	Jersey	Holstein	Brown Swiss	Jersey
Wt., 3 mos., kg.	103.5 kg.	74.2 kg.	65.5 kg.	95.3 kg.	89.0 kg.	56.7 kg.
Wt., 11 mos., kg.	333.3	303.3	210.0	302.7	310.2	197.3
Total Gain for 8 month period	203.3	229.1	144.5	207.4	221.2	140.6
Diff. from 50°F	----	----	----	22.9	7.9	3.9

TABLE 3b--TIME REQUIRED TO REACH 300 KG. FOR HOLSTEIN AND BROWN SWISS AND 200 KG. FOR JERSEY

	50°F (Months)	80°F (Months)
Holstein	9.5	11.0
Brown Swiss	11.0	11.0
Jersey	10.0	11.0

weight of 300 kg. The Jerseys took one month longer at 80° F, and the Brown Swiss made equivalent gains at both temperatures in approximately the same amount of time.

Instantaneous Percentage Rate of Growth vs. Age. The instantaneous percentage rate of growth presented in Figure 7 declined with advancing age in agreement with the law of diminishing increments, which states that growth rate increases at ever decreasing rates. The graph suggests that the instantaneous rate of growth decreased at a lower rate for the 80° F animals than for the 50° F animals after about 7½ months of age. The flattening of the slopes is particularly apparent for the average 80° F Jerseys' and Brown Swiss' growth rate values.

Monthly Increments in Weight, Height, and Chest Girth. Monthly increments in weight, height, and chest girth are shown in Figure 8. Moving averages of the data are used for smooth presentation of the time dependent trends. Unusual breed differences in weight gain per month occurred. For example, Holstins at 50° F had a much higher rate of gain until eight months of age than the 80° F Holsteins. The difference became less from nine to 12 months of age. The 50° F Jerseys maintained a higher growth rate until approximately nine months of age. Thereafter, the growth rate of these animals dropped abruptly. The 80° F rate of gain then became higher than the 50° F rate.

Body Weight vs. Chest Girth. Figure 9 represents the relation of body weight to chest girth in Holstein, Brown Swiss, and Jersey calves, based on the average of three animals of each breed. The data were plotted on log-log paper so that

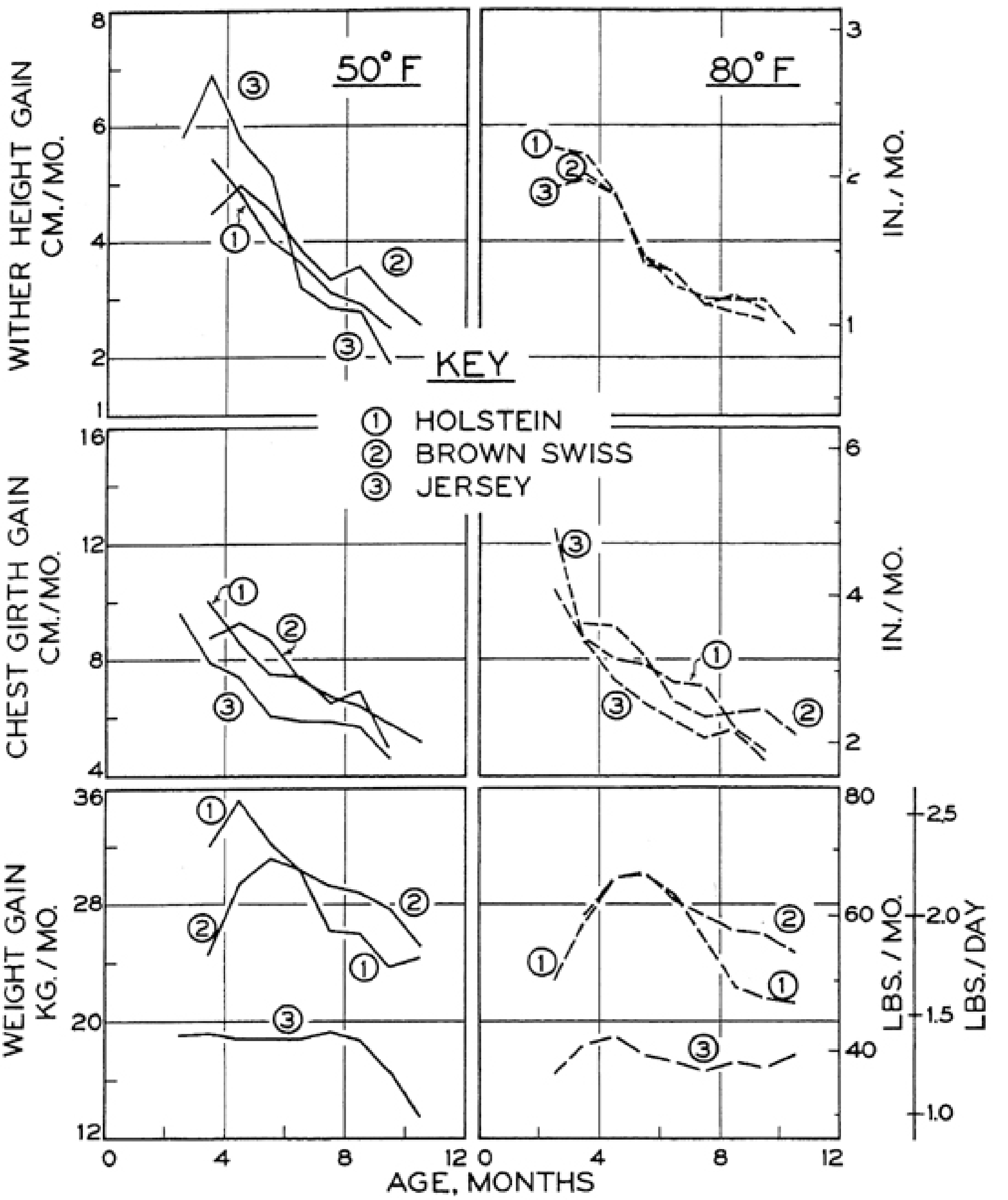

Fig. 8—Weight, chest girth, and wither height gain per month of Holsteins, Brown Swiss, and Jerseys raised at 50° F and 80° F based on three point moving averages.

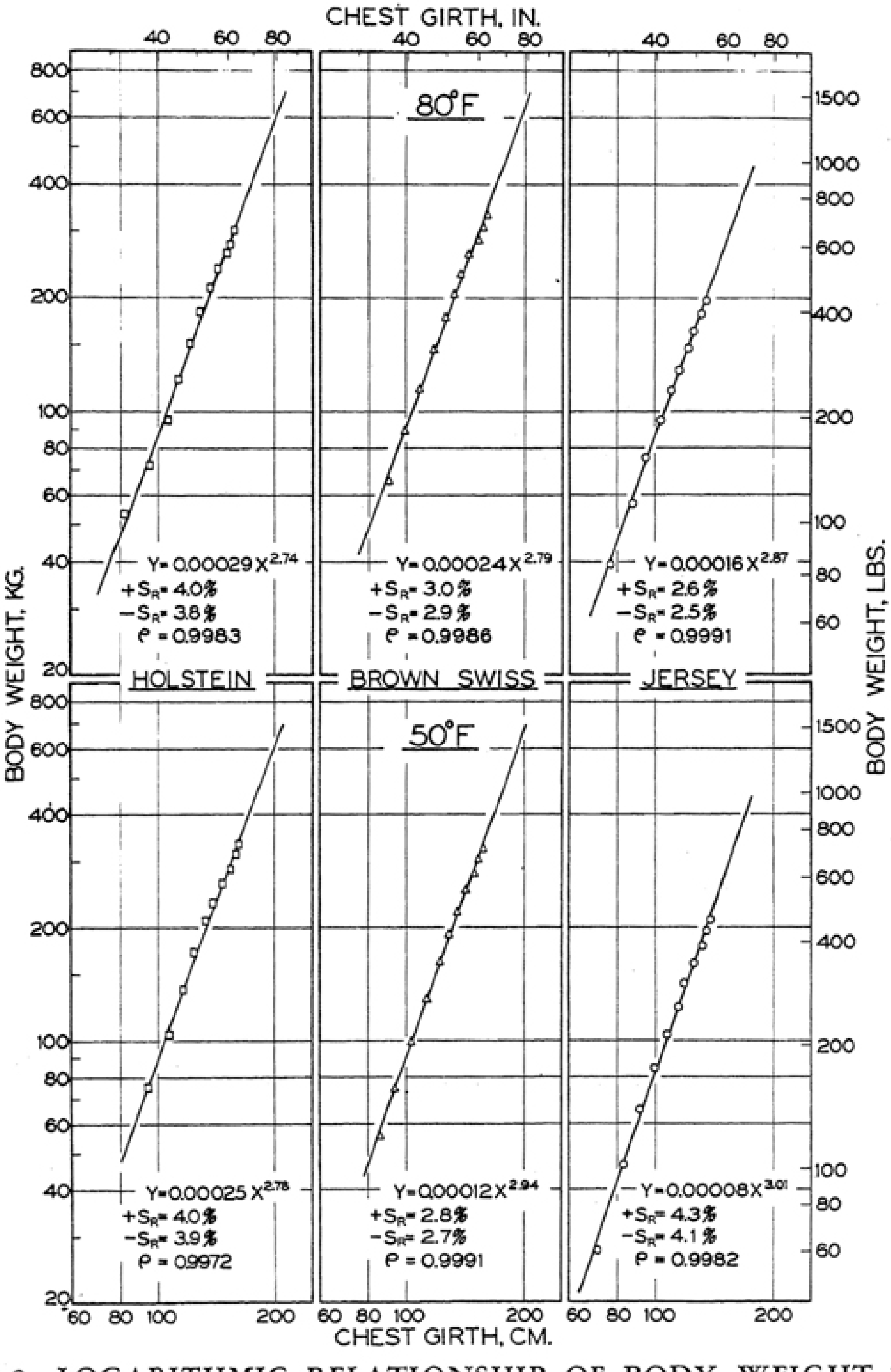

Fig. 9—LOGARITHMIC RELATIONSHIP OF BODY WEIGHT TO CHEST GIRTH OF HOLSTEIN, BROWN SWISS, AND JERSEYS RAISED AT 50° F AND 80° F. The relationship was expressed by the general equation $Y = aX^b$, Y representing body weight and X, chest girth, According to equation an increase of 1 percent in X would be associated with an increase of b percent in Y. For example, when the 50° F Holsteins' chest girth increases 1 percent, their body weight increased 2.78 percent.

they could be presented in the form of a straight line, or rectified. The parabolic equation, $Y = aX^b$ (logarithmic equivalent $\log Y = \log a + b \log X$), was then fitted to the data by the method of least squares. Included on the charts are the standard error of the estimate and rho, the correlation index. The correlations between body weight and chest girth were above 0.99 in every instance, indicating that body weight could be predicted from the chest girth with almost complete certainty. The parabolic equation given here generally means that an increase of 1 percent in X occurs with an increase of b percent in Y. Thus, in the example of the 50° F Holsteins, an increase of 1 percent in chest girth is associated with an increase of 2.78 percent in body weight. Data suggest a greater percentage increase of body weight per increase in chest girth for all breeds at 50° F, compared with those at 80° F.

Body Weight vs. Wither Height. Figure 10 is a log-log plot of body weight vs. wither height with the regression line figured from the same equation, $Y = aX^b$. Wither height correlates with body weight by an index of 0.98. The exponent (b) values relate the wither height to body weight by a power of 4. The values for chest girth are near 3.

Chest girth is considered nearest to the theoretical growth, i.e., "to meeting the dimensional analysis expectation that body weight varies with the cube of linear size," (Brody, 1945). Charts of the relationships (Figures 9 and 10) may be valuable for prediction purposes since the data were obtained under constant environmental conditions.

Ratio of Body Weight to Wither Height. Figure 11 represents the ratio of body weight in kilograms to wither height in centimeters. Height at withers is an index of bone growth and is relatively unaffected by nutritional factors. Therefore, it is an excellent estimate of the genetic size of an animal or breed.

An all-breed comparison of the animals at 50° F shows that the Holsteins had the greatest ratio of body weight to wither height; Brown Swiss, an intermediate ratio; and Jerseys, the lowest ratio. The difference in the Brown Swiss and Holstein ratios was due to body weight. Is the higher Holstein ratio at 50° F associated with or a reflection of heat intolerance at 80° F? Holsteins are generally acknowledged to be less heat tolerant, and they have a higher value. These Holsteins, which had the highest ratio at 50° F had, nevertheless, a lower ratio than the Brown Swiss at 80° F. Furthermore, considering only the ratios, young animals should be more heat tolerant and have correspondingly lower ratios than older animals. For clear interpretation, the ratios must be considered from the breed, environmental temperature, and age viewpoints.

Predicted Growth. Since animals could not remain in the laboratory until they reached maturity, prediction of mature weight were made on the basis of growth to one year of age. Table 4 shows genetic growth constants: predicted mature weight (A), percentage of monthly decline (k), and age in months at which 99 percent of the mature weight is attained. An important fact to consider, especially with reference to the prediction tables and curves, is that the values on

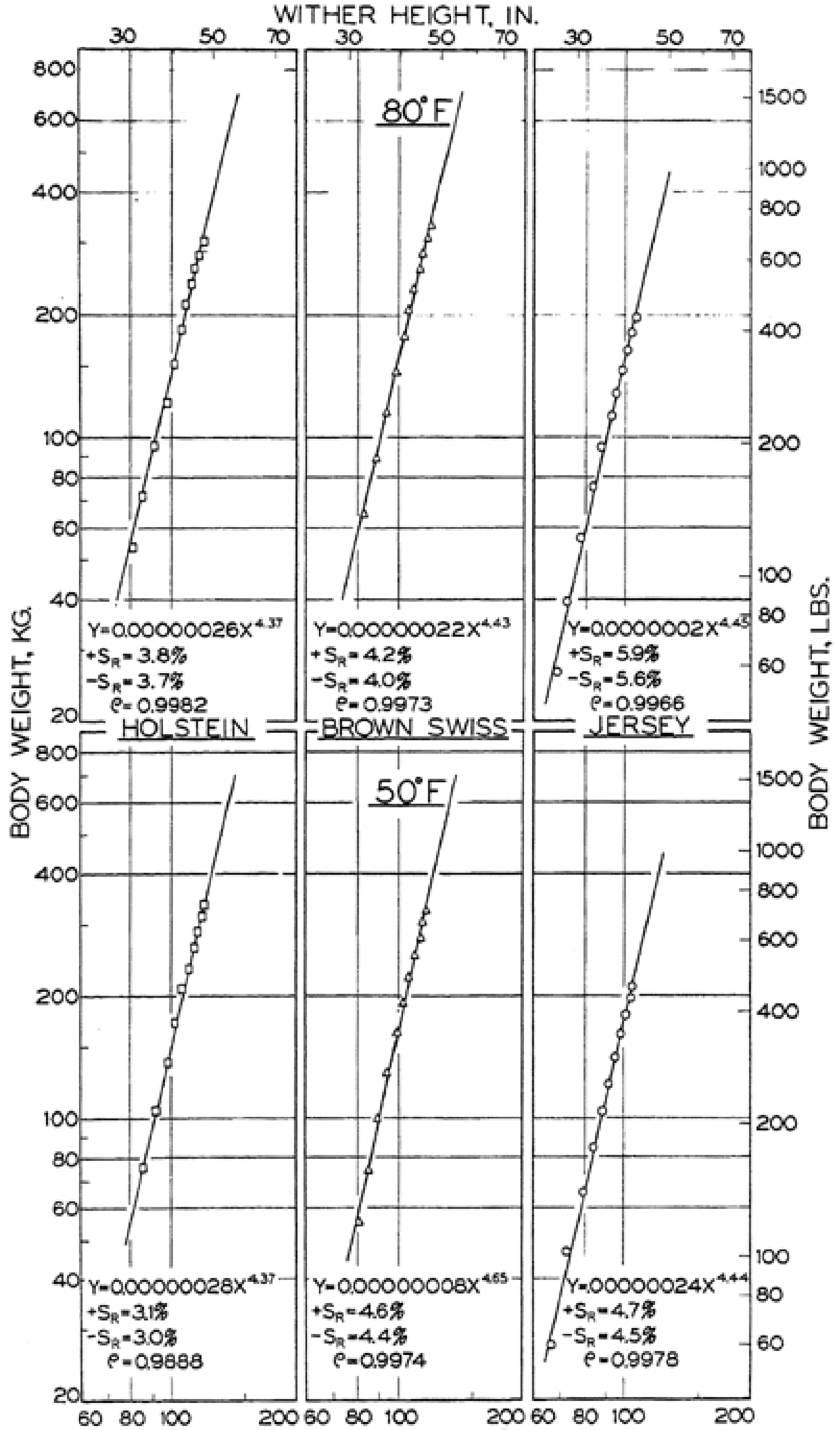

Fig. 10—LOGARITHMIC RELATIONSHIP OF BODY WEIGHT TO WITHER HEIGHT OF HOLSTEINS, BROWN SWISS, AND JERSEYS RAISED AT 50° AND 80°F. The relationship was expressed by the general equation $Y = aX^b$, Y representing body weight and X, wither height. According to equation an increase of 1 percent in X would be associated with an increase of b percent in Y. For example, for every increase of 1 percent in the 50° F Holsteins wither height, there is an increase of 4.37 percent in their body weight.

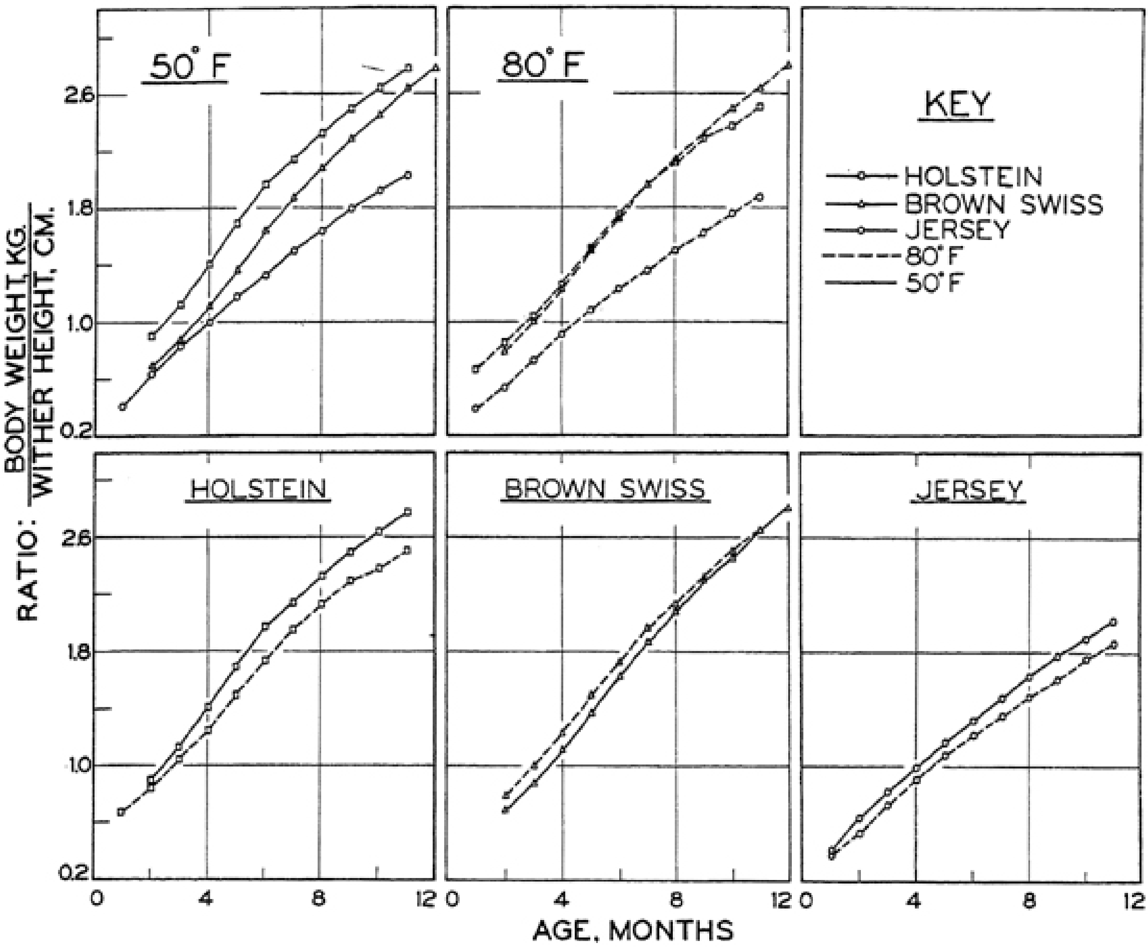

Fig. 11—RATIO OF BODY WEIGHT TO WITHER HEIGHT OF HOLSTEINS, BROWN SWISS, AND JERSEYS RAISED AT 50° F AND 80° F FROM ONE TO 11-12 MONTHS OF AGE.

TABLE 4--PREDICTION OF MATURE WEIGHT

Temp.	Breed	Predicted Mature Weight, kg.	lb.	Percentage of Monthly Decline	Age at 99% Mature Weight, mos.
50°F	Brown Swiss	700	1543	5.7	82.5
	Holstein	700	1543	6.2	74.7
	Jersey	500	1102	5.8	79.9
80°F	Brown Swiss	700	1543	6.3	74.6
	Holstein	660	1460	5.8	79.9
	Jersey	450	992	5.9	79.8

The k values were less sensitive to change than the age at mature weight. A wide range of age values gave only a small change in k, whereas a slight change in k resulted in a large change in age at mature weight. Animals attaining mature weight more rapidly had higher k values, i.e., a steeper slope.

which they were based were derived from animals experiencing constant environmental conditions. Using the modified exponential equation $W = A - B_e^{kt}$, one can predict the eventual mature weight of these animals had they been kept in the laboratory under these conditions.

Figure 12 presents the prediction curves expressing the modified exponential equation $W = A - B_e^{kt}$ for the three breeds raised at the two temperatures. A is the mature weight; k is the rate of monthly decline; B is derived from A–W when t is equal to O; t stands for age; and W, weight. Computation methods relevant to this equation have been described by Brody (1945) and by Ragsdale *et al.* (1957). Limits are imposed on the predictive value of the given equation because the data represent only the first 12 months of growth.

The predicted mature weight of both 80° F and 50° F Brown Swiss is the same, i.e., 700 kg. (1543 lbs.). The Holsteins' predicted mature weight differed by 40 kg. (88 lbs.), i.e., greater for the Holsteins raised at the cooler temperature; the Jerseys' differed by 50 kg. (110 lbs.) in the same direction, with the mature predicted weight of the 50° F group being 500 kg. (1102 lbs.).

DISCUSSION

Growth Comparisons. Both 12-month and mature weights are in reasonable agreement with actual measurements of female cattle recorded by Ragsdale (1934), Davis and Hathaway (1955), and Matthews and Fohrman (1954), who conducted investigations with similar feeding programs. However, the animals of the current study were somewhat heavier than the ones these authors cited. At 12 months of age, Ragsdale's Holsteins weighed 632 pounds and his Jerseys, 450 pounds, in comparison to the 793 and 483 pound weights of the 50° F Holsteins and Jerseys and the 716 and 478 pound weights of the 80° F Holsteins and Jerseys. Data of Davis and Hathaway showed that 12-month old Holsteins weighed 703 pounds on the average. Matthews and Fohrman's Jerseys of the same age weighed approximately 520 lbs., while their Holsteins weighed 714 pounds.

Compared to the 12-month weights recorded by Stallcup, Herman, and Ragsdale (1949), the 80° F Jerseys were approximately 54 pounds heavier and the 50° F Jerseys were approximately 40 pounds heavier. The 50° F and 80° F Holsteins were approximately 100 and 75 pounds heavier, respectively. Feeding conditions of the Stallcup study were similar to those of the present investigation in respect to grain and milk provisions The climatic laboratory animals were fed average quality of alfalfa *ad libitum,* but had no access to pasture or silage.

Table 5 shows a comparison of weight, wither height, and chest girth measurements of the several studies on Holstein and Jersey heifers at 12 months of age.

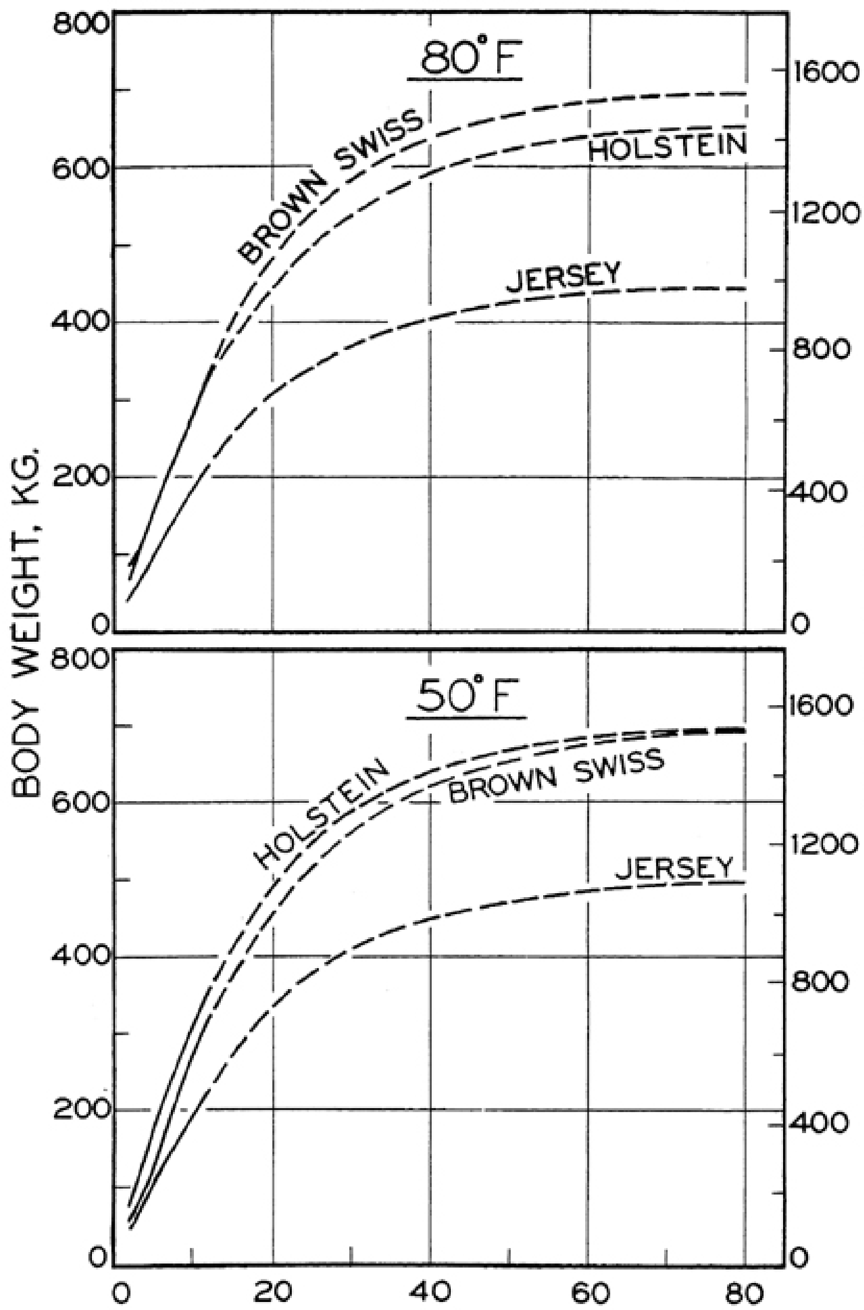

Fig. 12—PREDICTION CURVES. The smooth curves represent the equation $W = A - B_e^{kt}$ for Holstein, Brown Swiss, and Jersey heifers at 50° F and 80° F. The solid curves represent actual values, the dotted lines, predicted values.

TABLE 5--COMPARISON OF WEIGHT, CHEST GIRTH, AND WITHER HEIGHT DATA FROM INVESTIGATIONS CITED

Investigators	Weight, lbs.	Chest Girth, in.	Wither Height, in.
	Twelve Month Jersey Females		
Ragsdale, 1934	450	54	42.2
	*N:159	N:56	N:146
Stallcup, Herman, Ragsdale, 1949	439.3	54.3	41.0
	N:10	N:10	N:10
Matthews and Fohrman, 1954	520	----	----
(Beltsville Standards)	N:360	----	----
Johnson and Ragsdale, 1959	483	55.2	41.4
(50°F Raised Heifers)	N:3	N:3	N:3
Johnson and Ragsdale, 1959	478	54.6	42.1
(80°F Raised Heifers)	N:3	N:3	N:3
	Twelve Month Holstein Females		
Ragsdale, 1934	632	58.9	46.0
	N:200	N:59	N:183
Stallcup, Herman, Ragsdale, 1949	638	60.4	46.3
	N:18	N:18	N:18
Matthews and Fohrman, 1954	714	----	----
(Belstville Standards)	N:372	----	----
Davis and Hathaway, 1955	703	62.5	47.1
	N:242	N:229	N:229
Johnson and Ragsdale, 1959	793	65.1	48.3
(50°F Raised Heifers)	N:3	N:3	N:3
Johnson and Ragsdale, 1959	716	63.6	48.0
(80°F Raised Heifers)	N:3	N:3	N:3

* N: refers to number of animals measured.

With reference to mature body weights, Ragsdale (1934) found that mature Holstein and Jersey females weighed about 1370 and 930 pounds, respectively. Davis and Hathway (1955) observed that mature Nebraska female Holsteins weighed approximately 1494 pounds. The Beltsville Holsteins, as reported by Matthews and Fohrman, weighed 1513 pounds at 80 months of age, while the Jerseys weighed 1083. These findings may be contrasted to our predicted mature weights of 1543 and 1460 pounds for the 50° F and 80° F Holsteins, respectively, and 1102 and 992 pounds for the corresponding groups of Jerseys.

It is evident that both 12-month and predicted mature weights of the Holsteins and Jerseys raised in the climatic laboratory at either 50° F or 80° F were greater than those recorded in at least two of the previous studies cited (Ragsdale, 1934, Davis and Hathaway, 1955). They were generally the same or somewhat lower than the Beltsville standards. The management conditions, however, varied considerably.

Effect of Environmental Temperature Upon Growth. The results of this study in the climatic laboratory are in general agreement with those of Hancock and Payne (1955) who conducted a unique field investigation designed to measure the direct effects of climate on the growth of European-type cattle. Eight sets of twins were used. One twin of each set was placed at Sigatoka, Fiji Islands, and he other at Ruakura, New Zealand. During the growth period, the mean temperature at Sigatoka was 75° F with 80% relative humidity, while at Ruakura, it was 54° F with 84% relative humidity. Thus, temperature was the major recorded climatic variable.

These experimental conditions were somewhat comparable to those of the Missouri studies in which one chamber had a temperature of 80° F with a relative humidity of 54%, and the other was maintained at 50° F with 62% relative humidity. Because of the higher humidity in the Fiji Islands, an environmental temperature of 75° F, 80% relative humidity was likely more depressing than the constant 80° F and 54% relative humidity in the Missouri Climatic Laboratory.

Data at the end of the second phase of their study can be compared with data of this study on dairy calf growth under constant environmental conditions; both groups would be approximately one year of age. The weights of the Fiji group were depressed in comparison to those of the cooler New Zealand group and 50° F Missouri laboratory group. However, the fact that there were differences in feeding programs and that the Hancock and Payne animals were 7½ months of age before initiation of the experiment prevents close comparisons.

The Holstein growth responses are generally similar to data reported by Carneiro and Rhoad, 1936, who found that purebred Holstein calves in the tropics from imported dams show a decrease in growth rate, compared with such calves under temperate conditions. The depression of growth rate was accentuated after 6 months of age.

It appears that Holsteins, regardless of size or degree of maturity, are more affected by higher temperatures than are other breeds of corresponding age and maturity. For example, large, mature lactating Holstein cows are more affected than other breeds of the same age by high environmental temperatures (Ragsdale, *et al.,* 1949; Ragsdale, *et al.,* 1950; Worstell and Brody, 1953), and even small, immature Holstein calves are less heat tolerant than other calves, a fact which indicates emphatically that variables other than stage of maturity and associated size are involved in the phenomena related to heat tolerance.

Somewhat surprisingly, the Brown Swiss animals did exceptionally well at 80° F. This was the only breed not stressed by the high temperature. Admittedly, some of the superior performance at 80° F may be attributed to greater individual variability of the Brown Swiss.

Heat tolerance may be associated with metabolic efficiency, level of heat production, thyroid activity, etc. Further insights into the latter phenomena may be obtained from subsequent reports on this experiment.

It is evident from the data that in addition to "adapted" or genetic characteristics, physiological and biochemical adjustment or "acclimation" of the calves to the environmental temperatures occurred. These effects are obvious in the growth responses of the Holstein and Jersey calves. For example, following eight months of age the 50° F Jerseys had a daily rate of gain lower than that of the 80° F animals. Possible explanations are that: (1) the more rapidly growing animals reached a point of decreasing rate-of-gain sooner than the animals that made slower gains. (2) the 80° F Jerseys became acclimated to the higher temperature and gradually made up the gains that were lost when they were first exposed to 80° F.

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APPENDIX TABLE I--COMPOSITION OF CALF STARTER AND CALF AND HEIFER MIX

Starter		Calf and Heifer	
300.0 lbs.	Corn, dent, grade #2	480.0 lbs.	Corn
300.0 lbs.	Oats, not including Pacific Coast States	200.0 lbs.	Oats
100.0 lbs.	Wheat Bran, all analysis	200.0 lbs.	Wheat Bran
100.0 lbs.	Linseed meal, old process, all analysis	50.0 lbs.	Soybean Meal
50.0 lbs.	Soybean oil meal, 43% protein	50.0 lbs.	Linseed Meal
50.0 lbs.	Ground alfalfa meal, 17% protein	10.0 lbs.	Salt
50.0 lbs.	Dried Skim milk	10.0 lbs.	Bone Meal
27.5 lbs.	Blood flour or soluble blood meal	2.5 lbs.	Reinforced Cod Liver Oil
2.5 lbs.	Cod liver oil	500.0 lbs.	Foremost D & F Mix
10.0 lbs.	Bone meal	1502.5 lbs.	
10.0 lbs.	Salt		
500.0 lbs.	Foremost calf starter		
1500.0 lbs.	Total		

APPENDIX TABLE II--BODY WEIGHT OF HOLSTEIN, BROWN SWISS, AND JERSEY CALVES AT 50°F FROM ONE TO TWELVE MONTHS OF AGE
(Body weight of calves read from graphs*)

Age, Mos.	1	2	3	4	5	6	7	8	9	10	11	12	13
Calf No.						(Kilograms)							
BS-17	----	59.5	78.0	101.0	129.0	159.0	185.0	211.0	243.5	272.0	294.5	313.0	-
BS-18	----	53.5	74.0	103.0	133.0	169.0	202.0	231.5	258.0	282.0	308.5	334.0	-
BS-23	----	53.5	70.5	93.0	126.0	159.0	190.0	219.0	249.0	281.0	307.0	329.5	-
Av.	----	55.50	74.17	99.0	129.33	162.33	192.33	220.50	250.17	278.33	303.33	325.50	-
H-845	----	85.0	115.0	153.0	188.0	226.0	252.0	277.0	299.5	318.0	336.0	353.0	-
H-847	----	72.0	100.0	133.0	164.5	201.5	226.0	261.0	287.5	314.5	335.0	365.0	-
H-848	----	69.5	95.5	125.0	223.0	162.0	198.5	249.5	275.0	302.5	330.5	363.0	-
Av.	----	75.50	103.50	137.0	171.50	208.67	233.66	262.50	287.33	311.67	333.83	360.33	-
J-633	34.0	50.0	71.0	90.5	110.0	130.0	149.0	170.5	190.5	209.0	223.0	231.5	-
J-635	23.0	53.5	71.0	89.0	108.0	125.0	143.5	159.5	177.5	193.5	209.0	220.0	-
J-636	25.0	36.0	54.5	74.0	93.5	110.0	129.0	151.0	170.5	187.0	198.0	207.5	-
Av.	27.33	46.50	65.50	84.50	103.83	121.67	140.50	160.33	179.50	196.50	210.0	219.67	-
BS-19	----	70.0	93.0	116.0	147.0	180.0	210.0	238.0	264.0	289.5	313.0	335.0	-
BS-20	----	56.0	78.0	103.5	131.0	156.0	178.0	203.0	230.0	254.5	280.0	302.0	-
BS-21	----	70.0	96.0	127.0	164.0	199.0	230.0	256.0	286.0	309.5	337.5	365.0	-
Av.	----	65.33	89.0	115.50	147.33	178.30	206.0	232.33	260.0	284.50	310.16	334.0	-
H-846	58.5	78.5	104.0	135.0	165.0	201.0	231.5	253.0	272.5	283.0	303.0	327.0	-
H-849	51.5	67.5	89.0	113.0	142.0	171.0	197.0	223.5	250.0	267.0	293.0	319.0	-
H-850	51.0	70.0	93.0	119.0	149.0	182.0	208.0	238.0	263.0	287.5	312.0	331.0	-
Av.	53.67	72.0	95.33	122.33	152.0	184.66	212.17	238.17	261.83	279.17	302.67	325.67	-
J-637	23.0	30.0	41.5	55.0	71.0	88.0	99.0	114.0	131.0	150.0	169.0	188.0	-
J-631	33.0	50.0	71.0	93.0	113.0	133.0	149.0	166.0	180.0	197.0	210.0	230.0	-
J-634	23.5	38.0	57.5	79.0	100.0	120.5	139.0	160.0	180.0	196.0	213.0	233.5	-
Av.	26.50	39.33	56.67	75.67	94.67	113.83	129.0	146.67	163.67	181.0	197.33	217.17	-

* Twice-weekly datum points were plotted on a graph. The datum points from one to twelve months of age were read from this plot according to the average birthday.

APPENDIX TABLE III--CHEST GIRTH OF HOLSTEIN, BROWN SWISS, AND JERSEY CALVES AT 50°F FROM ONE TO TWELVE MONTHS OF AGE*
(Read from graph** according to average birthday)

Age, Mos.	1	2	3	4	5	6	7	8	9	10	11	12	13
Calf No.						(Centimeters)							
BS-17	----	86.5	93.75	103.25	112.60	119.50	127.20	131.50	139.99	145.1	147.1	153.7	-
BS-18	----	88.25	95.0	104.60	114.75	124.20	130.50	137.90	142.90	149.1	154.3	158.3	-
BS-23	----	84.40	91.75	100.30	110.80	120.30	129.10	134.10	141.50	150.0	154.5	159.0	-
Av.	----	86.38	93.50	102.72	112.72	121.33	128.93	134.50	141.46	148.07	151.97	157.0	-
H-845	----	97.0	110.5	119.0	126.3	135.4	137.5	149.0	153.9	157.0	162.1	164.0	-
H-847	----	93.0	106.6	113.9	123.2	131.2	138.5	145.0	152.0	160.7	161.0	165.0	-
H-848	----	93.0	103.9	113.9	123.3	132.2	138.7	145.0	151.5	159.2	160.9	167.0	-
Av.	----	94.33	107.0	115.60	124.27	132.93	138.23	146.33	152.47	158.97	161.33	165.3	-
J-633	75.1	86.9	93.0	101.2	108.9	115.9	121.3	127.7	134.0	139.2	141.8	144.0	-
J-635	67.4	86.0	95.0	103.3	109.2	114.3	117.7	125.0	130.0	132.8	137.8	140.0	-
J-636	69.4	75.1	84.0	93.4	100.9	108.7	113.5	119.7	128.0	131.5	133.9	137.0	-
Av.	70.63	82.67	90.67	99.30	106.33	112.97	117.50	124.13	130.67	134.50	137.83	140.3	-
BS-19	----	92.5	100.3	110.2	117.7	128.0	132.3	138.0	144.0	148.8	158.0	161.7	-
BS-20	----	85.0	95.0	101.8	112.6	119.6	125.7	132.0	138.7	145.0	149.0	154.6	-
BS-21	----	91.5	99.3	109.4	121.6	138.7	136.6	141.0	147.6	157.2	161.1	162.6	-
Av.	----	89.67	98.20	107.13	117.30	125.43	131.53	137.0	143.43	150.3	156.03	159.63	-
H-846	89.0	97.8	107.0	116.2	124.0	132.8	140.0	145.9	152.2	154.0	157.9	160.5	-
H-849	87.0	93.1	104.0	110.8	118.3	126.1	134.0	138.9	148.5	150.7	156.2	159.7	-
H-850	70.0	94.1	104.5	112.8	121.3	128.7	136.0	143.8	150.7	155.5	158.6	164.7	-
Av.	82.0	95.0	105.17	113.27	121.20	129.20	136.67	142.87	150.47	153.40	157.57	161.6	-
J-637	55.0	70.6	80.0	85.5	94.2	99.2	105.0	110.0	115.0	127.0	128.2	133.0	-
J-631	62.6	83.0	94.2	101.5	111.2	117.0	122.0	127.9	130.6	133.7	137.1	142.9	-
J-634	53.5	75.8	87.7	96.3	101.9	111.1	115.0	122.8	129.0	131.9	136.4	140.0	-
Av.	57.03	76.47	87.30	94.43	102.43	109.10	114.0	120.23	124.89	130.87	133.90	138.6	-

* Twelve-month Holstein and Jersey values approximate actual measurements as closely as possible. The 50°F Holsteins were twelve months old on Sept. 9, and the Jerseys, on Sept. 16. Therefore, the final measurements, recorded Sept. 2, were taken when the Holsteins were eleven months, three weeks old and the Jerseys were 11 1/2 months old.

** Bi-monthly datum points were plotted on a graph. The datum points from one to twelve months of age were read from this plot according to the average birthday.

APPENDIX TABLE IV--WITHER HEIGHT OF HOLSTEIN, BROWN SWISS, AND JERSEY CALVES AT 50°F FROM ONE TO TWELVE MONTHS OF AGE*
(Read from graph** according to average birthday)

Age, Mos.	1	2	3	4	5	6	7	8	9	10	11	12	13
Calf No.						(Centimeters)							
BS-17	----	81.8	85.4	89.0	93.9	98.3	102.5	104.3	107.8	113.1	113.2	116.0	-
BS-18	----	81.2	84.5	90.2	95.2	99.8	103.9	107.1	111.3	114.6	116.3	118.0	-
BS-23	----	79.3	83.0	88.5	93.6	99.7	102.0	106.0	108.7	112.8	114.7	116.7	-
Av.	----	80.77	84.30	89.23	94.23	99.27	102.80	105.80	109.27	113.50	114.73	116.90	-
H-845	----	88.0	94.4	100.3	104.2	108.2	111.5	113.8	116.0	119.1	121.7	124.0	-
H-847	----	83.6	89.8	96.5	100.2	105.2	108.9	111.8	115.0	117.1	119.5	122.0	-
H-848	----	84.0	90.1	95.3	100.1	104.0	107.8	111.7	114.5	118.3	118.6	122.3	-
Av.	----	85.20	91.43	97.37	101.50	105.80	109.40	112.43	115.17	118.17	119.93	122.8	-
J-633	68.9	74.7	81.2	85.9	89.4	94.1	96.7	100.9	103.8	106.0	105.8	106.7	-
J-635	64.7	72.8	80.1	85.0	88.2	90.6	92.9	94.4	96.3	100.6	100.3	102.3	-
J-636	66.9	69.7	76.5	82.0	86.7	90.0	94.5	97.8	100.3	102.5	104.0	106.2	-
Av.	66.83	72.40	79.27	84.30	88.10	91.57	94.70	97.70	100.13	103.03	103.37	105.1	-
BS-19	----	86.0	90.5	95.0	99.8	104.4	106.4	110.1	115.0	117.3	119.0	121.3	-
BS-20	----	82.0	87.0	92.5	97.5	101.7	103.7	107.2	111.1	113.2	117.0	119.2	-
BS-21	----	81.5	88.2	93.2	98.7	102.9	104.5	107.8	110.0	110.9	115.9	117.3	-
Av.	----	83.17	88.57	93.57	98.67	103.0	104.87	108.37	112.03	113.80	117.30	119.27	-
H-846	83.4	87.4	94.3	100.7	104.9	108.4	109.5	113.9	116.0	121.5	121.6	123.2	-
H-849	81.2	84.9	89.8	96.5	100.0	103.9	106.6	111.0	112.4	114.0	119.3	121.3	-
H-850	77.5	82.9	89.8	95.4	99.9	105.3	108.8	111.3	115.2	116.9	120.6	121.3	-
Av.	80.70	85.07	91.30	97.53	101.60	105.87	108.30	112.07	114.53	117.47	120.50	121.9	-
J-637	67.7	69.3	74.1	78.7	83.0	87.1	89.9	93.0	96.0	98.4	102.2	103.8	-
J-631	74.3	79.0	84.7	90.4	93.4	98.8	100.6	103.2	106.9	109.9	111.5	111.9	-
J-634	64.0	68.4	75.6	81.4	85.9	91.8	93.7	97.2	101.0	101.0	103.5	105.5	-
Av.	68.67	72.23	78.13	83.50	87.43	92.57	94.73	97.80	101.3	103.1	105.73	107.1	-

* Twelve-month Holstein and Jersey values approximate actual measurements as closely as possible. The 50°F Holsteins were twelve months old on Sept. 9, and the Jerseys, on Sept. 16. Therefore, the final measurements, recorded Sept. 1, were taken when the Holsteins were eleven months, three weeks old and the Jerseys were 11 1/2 months old.

** Bi-monthly datum points were plotted on a graph. The datum points from one to twelve months of age were read from this plot according to the average birthday.

APPENDIX TABLE V--VARIANCE ANALYSIS OF TEMPERATURE AND AGE EFFECTS ON BODY WEIGHT (80^oF vs. 50^oF ANIMALS)

Source of Variation	d.f.	Sum of Squares	Mean Square	F	P
Total					
Brown Swiss	21	171297.53			
Holstein	21	167367.99			
Jersey	21	70188.64			
Temperature					
Brown Swiss	1	791.84	791.84	96.21	0.01, 0.05
Holstein	1	2607.07	2607.07	53.79	0.01, 0.05
Jersey	1	585.45	585.45	73.92	0.01, 0.05
Age					
Brown Swiss	10	170423.40	17042.34	2070.76	0.01, 0.05
Holstein	10	164276.25	16427.63	338.92	0.01, 0.05
Jersey	10	69524.04	6952.40	877.83	0.01, 0.05
Interaction					
Brown Swiss	10	82.89	8.23		
Holstein	10	484.67	48.47		
Jersey	10	79.15	7.92		