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J. H. LONGWELL, *Director*

Environmental Physiology

With Special Reference to Domestic Animals

XII. Influence of Increasing of Temperature, 40° to 105° F on Milk Production in Brown Swiss Cows, and on Feed and Water Consumption and Body Weight in Brown Swiss and Brahman Cows and Heifers

A. C. RAGSDALE, H. J. THOMPSON, D. M. WORSTELL AND SAMUEL BRODY

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THE NATURE OF THE DATA AND METHODS OF ANALYSIS

This bulletin is one in a series of progress reports made at the completion of appropriate experimental periods. This report covers the period February 6 to June 9, 1950, with temperature levels from 40° to 105°F as shown in Table 1 and Fig. 1. Data were obtained on three high-milking Brown Swiss cows[1] (two of which were on Register of Production Test), three Brown Swiss heifers[1], three Brahman cows[1] (dry), and three Brahman heifers[1] (daughters of the cows). Table 2 gives pertinent information on these 12 animals.

The data in each of these separate reports are, in themselves, not suitable for estimating the statistical parameters that characterize populations. This is because of the small number of animals used; because the animals were not selected at random; because such estimates based on the assumption that the distribution of the deviations from the mean accords with Gauss's Law of Errors, and this law may be irrelevant to the rate-of-progress data conditioned by many genetic and environmental or "genotrophic" elements, at least not until it is shown otherwise by sufficient replication.

The analysis of the data presented in each of these bulletins is, therefore, necessarily confined to the study of *individual reactions curves or trends.* For instance, the milk production of each individual is plotted against advancing time and/or temperature, and conclusions are drawn by study of each curve. If, for example, the lactation curve shows a relatively abrupt change to a steeper slope at 85°F, it is tentatively concluded that the *critical temperature of lactation* for the given individual under the given condition is 85°F.

The conclusion that the *critical temperature*—a very important physiologi-

[1]Grateful acknowledgments are made to the owner of the Brown Swiss cattle, Mr. H. L. Dannen of the Dannen Research Farm, St. Joseph, Missouri, for furnishing these cattle for this experiment, and also for furnishing the milk and butterfat production records on these cows for the preceding lactation period here used as non-experimental controls. Grateful acknowledgments also are made to Mr. J. V. Gates, Poteet, Texas, for furnishing the Brahman cattle for this experiment.

TABLE 1.--TEMPERATURE CALENDAR, FEBRUARY 6 TO JUNE 9, 1950

Time Schedule		COWS (Chamber II)		HEIFERS (Chamber I)	
From 3 p.m. on	To 3 p.m. on	Temperature °F	R. Humidity %	Temperature °F	R. Humidity %
February 6	March 3	40	61	40	64
March 3	March 17	50	58	50	65
March 17	March 31	60	70	60	76
March 31	April 14	70	70	70	72
April 14	April 28	80	67	80	69
April 28	May 5	85	68	85	69
May 5	May 12	90	66	90	62
May 12	May 15	95	59		
May 15	May 17	100	56		
May 17	May 18	105*	55		
May 18	May 19	decreased to 80 (av. 90)	53		
May 19	May 25	72	72		
May 25	May 26	decreased to 50 (av. 57)	58		
May 26	June 9	40	63		
May 12	May 19			89	64
May 19	May 22			95	48
May 22	May 24			100	56
May 24	May 25			105	51
May 25	May 26			decreased to 60 (av. 75)	65
May 26	June 9			40	66

* Temperature was increased gradually from 3 p.m. on May 17 (100°) to 5 p.m. May 18 (105°) and remained at 105° until 3 p.m. on May 18.

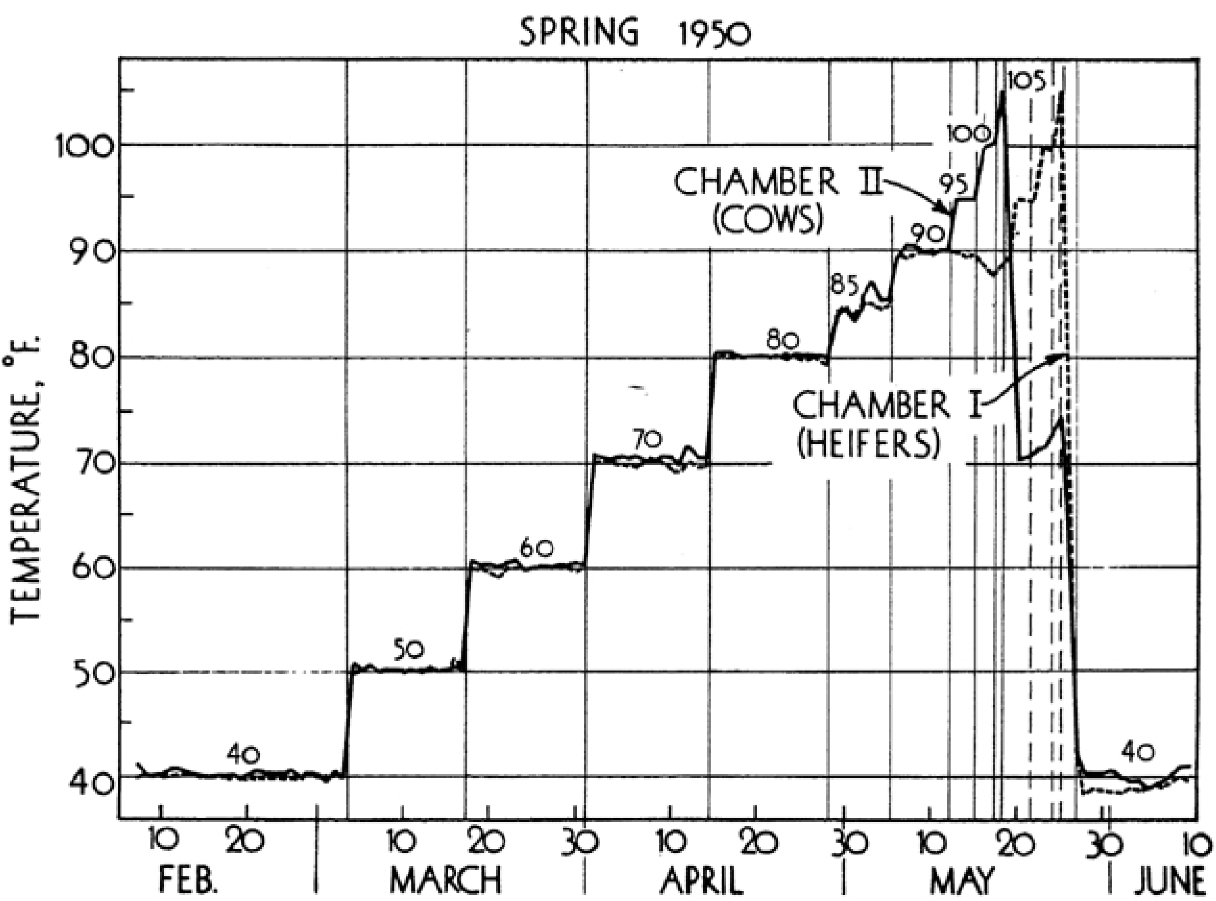

Fig. 1.—Time and temperature schedule. See Table 1 for numerical details. The heifers were in Chamber I (broken curve) and the cows were in Chamber II (continuous curves).

TABLE 2.--THE HISTORY OF THE COWS

Cow No.	Birth Date	Date of Last Calving	Number of Previous Lactations	Date of Last Breeding	At Beginning of Experiment: Approximate Age	At Beginning of Experiment: Body Weight Lbs.	Average During Month of January: Milk, lbs.	Average During Month of January: Butterfat, %
Cows					Years			
*Brown Swiss 16	Feb. 18, 1944	Dec. 5, 1949	3	July 8, 1950	6	1350	48.7	4.2
Brown Swiss 20	July 3, 1943	Dec. 11, 1949	3	June 22, 1950	6 1/2	1270	49.7	4.2
*Brown Swiss 24	Oct. 20, 1943	Nov. 15, 1949	3	Jan. 25, 1950	6 1/4	1410	42.6	3.8
Brahman 189	Feb. 13, 1947	Apr. 27, 1949	1	Nov. 25, 1949	3	940	dry after	
Brahman 190	Jan. 25, 1947	Apr. 25, 1949	1	Sept. 17, 1949	3	980	first lactation	
Brahman 209	May 6, 1947	Apr. 30, 1949	1	Sept. 17, 1949	2 3/4	930	(Aug. 15, 1949)	
Heifers					Months			
Brown Swiss 1	July 4, 1949				7	410		
Brown Swiss 2	July 13, 1949				7	340		
Brown Swiss 3	July 18, 1949				6 1/2	370		
Brahman 1	May 7, 1949				9	500		
Brahman 2	April 30, 1949				9	410		
Brahman 3	April 25, 1947				9	410		

* On Register of Production Test.

cal constant—occurs in a given breed, at a given temperature, as at 85°F, is by no means certain because factors other than temperature, especially time, would shape the curve and influence the position of the apparent change in slope. For instance, during the *time* that the animals are exposed to the various temperature levels and their reactions measured, they are also advancing in their stages of lactation and gestation and, depending on their adaptability, they are being acclimatized or deteriorated by the successive time exposures. The critical temperature is, therefore, likely to be not a point but a zone for an individual animal. The zone of change in slope of the individual cow would be broadened, masked, and distorted by averaging the values for many animals[2].

While the data and curves in each report are not by themselves suitable for computing estimates of biostatistical interest, they do furnish:

(1) Graphic reaction trends of *individual* animals to changing temperature, which give insight into the involved physiological processes and shelter needs.

(2) First approximations to the way different individuals of different breeds of different body weight and age, different levels of milk yield, and so on, react to changing temperature; the interest, of course, centers on the *critical temperature* and on the *temperature of maximal productivity*.

(3) Pilot-plant data for orientation and guidance in further research.

(4) Data for successive replications, which will eventually meet the needs for intensive statistical analysis and for broad integration of the material into a science of animal climatology, a basis for shelter engineering.

[2]Example of averaging which distorts the physiological significance of a rate-of-progress curve: The pubertal growth spurt in different children occurs at any year between ages 10 and 16 years, depending on many factors. If the growth data of many children are averaged, the individual pubertal growth spurts lose their identity into an average which spreads over the entire age interval 10 to 16 years. The average curve has a different appearance from the actual, the physiological, curve of the individual child. A physiologic phenomenon is thus masked and distorted by averaging.

The *Brahman* cows were investigated because, as explained in Res. Bul. 460, they were evolved in tropical India and are uniquely heat tolerant. The *Brown Swiss* cows were investigated because they are thought by some students of evolution of cattle to be related to the Brahmans, that they evolved from the same *Bos Longifrons* stock and so, perhaps, are more heat tolerant than the other European breeds[3]. This remains to be demonstrated. At any rate, it seemed important to investigate them, to find answers to the questions: (1) Are these breeds more heat tolerant than others and to what extent? (2) If they are, what makes them more tolerant; what are the mechanisms thereof?

We were interested in including the heifers in this experiment to find out whether some reaction peculiarity, such as decreasing water consumption in the high-milking cows with increasing temperature above 80°F, was a breed manifestation or was it associated with the lactational process. The heifers were open yearlings; therefore, if the decreased water consumption with increasing temperature in the Brown Swiss cows is associated with decreased milk production, the heifers should not show it. The heifers thus served as non-milking controls. The other items of interest about the heifers relate to differences in age (growth), weight, and surface area. The heifers should be more heat tolerant than the cows because being smaller they have a larger area per unit weight.

The animals in this experiment were managed like those in the preceding experiment (Missouri Res. Buls. 425, 449, and 460) with the exception that two of the Brown Swiss cows were on Register of Production Test and were fed grain more liberally as was done before they were placed in the laboratory. Grated alfalfa hay was fed *ad libitum*; all left-over hay was air-dried for three days before weighing and deducted from the amount offered. Grain mix, includ-

[3]Mr. G. D. Davis quoted (in a letter of October 23, 1950, to SB) from page 212 of the 1910 Report of the Bureau of Animal Industry, U. S. Dept. of Agriculture, that, according to Keller, Brown Swiss cattle were evolved from the same *Bos Longifrons* stock as the Zebu cattle of Asia and Africa and have some similar characteristics; he also quoted from Prof. G. W. Salisbury (The Brown Swiss Bul., *23*, 11, June 1945, and *24*, 17, January 1946) that the success of his dairy improvement program in Greece is due in no small part to the high heat tolerance of Brown Swiss cattle; he also quoted from the June 1947, Special Report of Inter-American Affairs, Food Supply Division, that Brown Swiss cattle in Scipa's cattle import program in Peru did better than Herefords. Mr. Davis also quoted evidence to the effect that Brown Swiss cattle did better than other European breeds in subtropical Venezuela. Prof. J. P. LaMaster observed (in a letter of October 11, 1950, to SB) that "Brown Swiss cattle lie down out in the pasture during the summertime without seeking the shade like cattle of other breeds". The tolerance of Brown Swiss cattle to strong sunlight—as well as to cold—may be inferred from the fact that they graze on the high Swiss mountains, exposed to both strong sunlight and cold winds. But what are the physiological mechanisms of the alleged tolerance of Brown Swiss cattle to both heat and cold? Dr. T. M. Bettini (Chief of the Animal Husbandry Department in the Instituto Agronomico per l'Africa Italiana, Florence, Italy) in a personal discussion of the problem expressed the opinion that physiological adaptation to a given environment is dependent mostly on relatively recent domestication characteristics rather than on remote origins of environments. For instance, some *Bos indicus* in the North Indian mountain regions are cold adapted; and some *Bos taurus*, like the Italian (Tuscany) Maremmana, Brazilian Caracu (from Portugal), and Colombian Orejinegro (from Spain) are heat tolerant. The *physiological* adaptation to high temperatures may, of course, be at the expense of *economic* efficiency (as high milk yield). The Brown Swiss are less adapted to warm southern Italy and Libya than local Italian cattle.

ing cod liver oil supplement (as reported in Table 3, Res. Bul. 425), was fed twice daily. The cows (but not the heifers) were fed two pounds dry beet pulp daily. Water was provided at all times in individual drinking cups; time and amount drank was automatically recorded. (See Res. Bul. 460 for further details on the water consumption recorder.)

DATA AND THEIR GRAPHIC ANALYSIS

Cows

Milk Production Levels in the Brown Swiss Cows.—The curves of milk production of the three Brown Swiss cows are charted in Fig. 2 and the numerical values for the different temperature levels are given in Table 3. The left side of Fig. 2 represents the absolute milk yield and butterfat percentage; the right side, the ratios of milk production observed this year under the laboratory conditions to the milk production recorded for the corresponding lactation stages of the preceding year obtained under good farm conditions at the Dannen Research Farm[1]. The preceding year's milk production of each animal under good farm conditions was thus used as "control" for this year's production for the same animal under laboratory conditions.

The left side of Fig. 2 shows that the milk yield declined slowly with increasing temperature from 40°F to 85°F. After 85°F the yield began a rapid decline with further increase in temperature to 105°F. The *first experimental approximation* to the *critical temperature* of milk production in the given three 1300-1400-pound Brown Swiss cows producing 40 to 50 lbs. milk a day under the given conditions is, then, between 85° to 90°F.

The butterfat per cent was roughly constant from 50° to 90°F, and thereafter spurted suddenly to almost twice the original value by 105°F.

Upon lowering the temperature, the milk yield and butterfat percentage returned quickly to the normal level.

Milk Production Efficiency in the Brown Swiss Cows.—The efficiency of a process is defined by the ratio of the energy output (here milk energy produced) to energy input (here TDN energy consumed). Dairymen prefer to define efficiency by the reciprocal of this ratio, namely by the ratio of feed input to milk output. If the animal gains or loses weight in the process, a correction should be made for the energy stored in or lost by the body.

Fig. 3 represents the course of efficiency with increasing time and temperature graphically. In the lower half the curves of milk production and of TDN consumption are plotted in terms of percentages of their levels at 50°F. The breaks in the curve for milk production and TDN consumption occurred at 85°F. When the temperature was increased to 105°F, the milk production decreased to 20 or 40 per cent and the TDN consumption to 5 or 10 per cent of the 50° level. As the feed consumption rate declined more steeply than the milk production rate, the animals must have lost body weight with increasing temperature (as shown in Fig. 4).

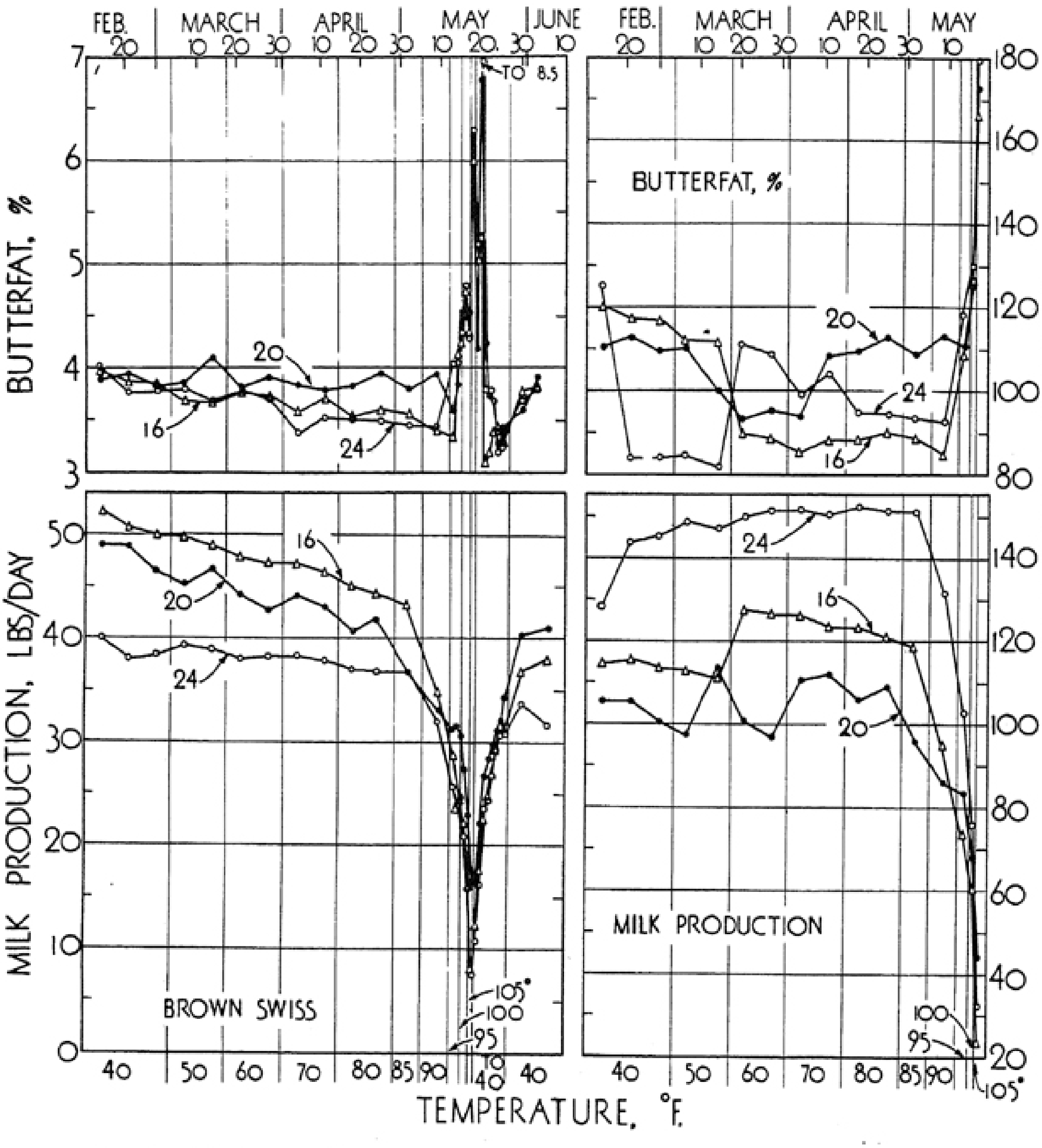

Fig. 2.—Absolute milk production and butterfat percentages of the Brown Swiss cows (left-hand section). The right-hand sections show a comparison of the milk and butterfat data obtained in our Laboratory (experimental lactation) with that of the corresponding month of the preceding lactation (obtained under the usual good farm conditions at the Dannen Research Farm) in terms of percentage ratios.

The upper right curve in Fig. 3 shows how the efficiency of milk production (ratio of milk energy output to TDN energy input) changed with increasing temperature. The upper left curves similarly show the pounds feed (TDN) consumed per pound of 4 per cent fat milk (FCM) produced. The *apparent* efficiency of milk production depends on whether or not correction is made for body weight loss with increasing temperature. The broken curves in the upper segment of Fig. 3 show that if correction is made for body weight

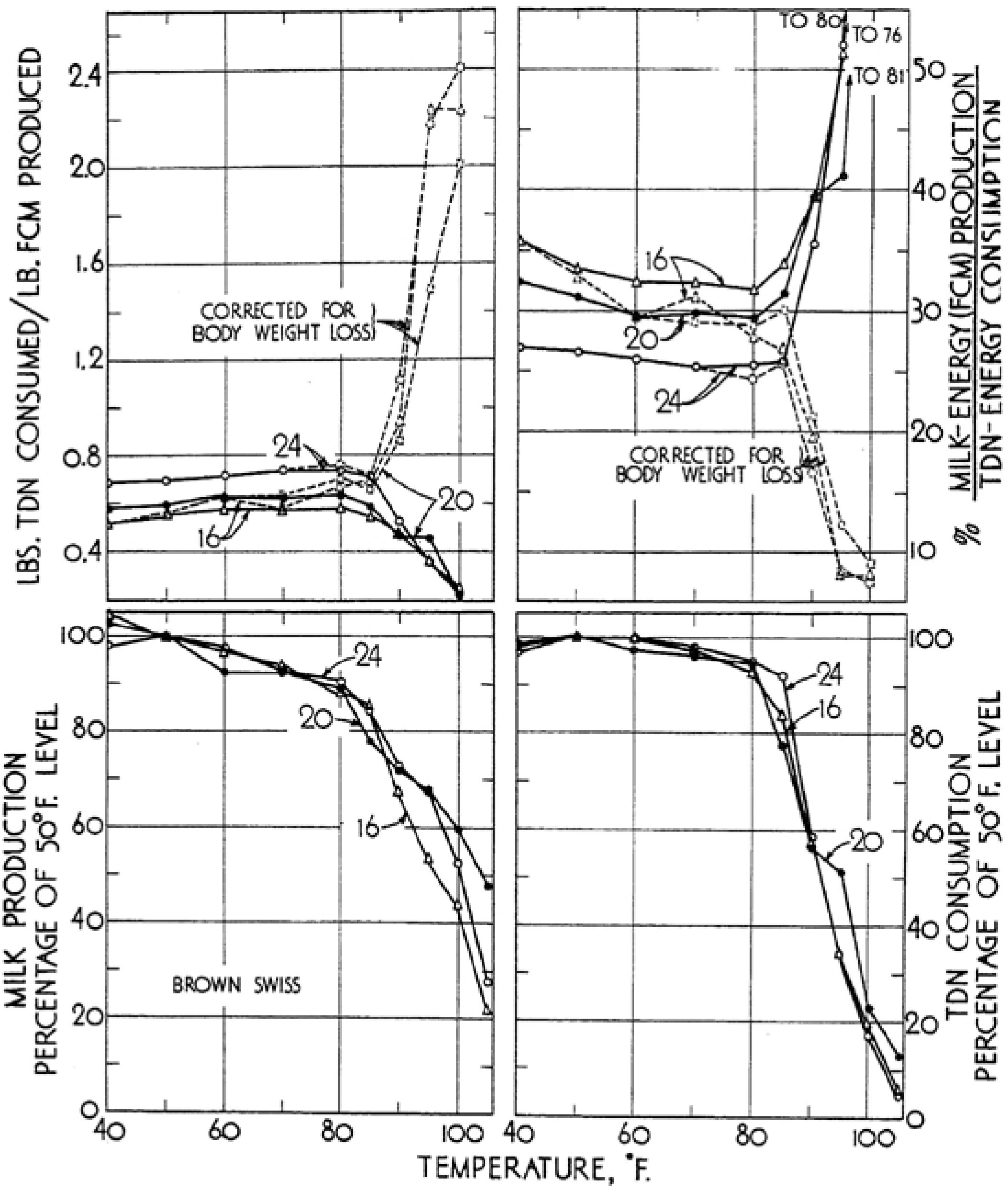

Fig. 3.—The curves on Brown Swiss cows for milk production (lower left) and TDN consumption (lower right) represented in terms of percentages of the levels at 50°F as function of temperature. The energetic efficiency of milk production (upper right) represents the ratio of milk energy produced to TDN energy consumed; the feed cost of milk production (upper left) represents the pounds of TDN consumed per pound FCM produced. The continuous curves represent the ratios before correcting for body weight loss and the broken curves after correction. (This correction was made by adding to the total TDN consumed a value obtained by multiplying 2.18 by body weight loss in lbs.; for further explanation, see pp. 839-41 of Brody's "Bioenergetics and Growth".)

loss[4], the efficiency declines or feed cost of milk production increases rapidly with increasing temperature; if, however, no correction is made per body-weight loss, the apparent efficiency increases, or feed cost of milk production decreases, rapidly with increasing temperature.

[4]One pound body weight loss was assumed to be equivalent to 2.18 lbs. TDN. (See page 840 in Brody's "Bioenergetics and Growth", Reinhold, New York, 1945.) This assumption does not provide for changes in fill, body water, or composition of the tissues; and is in error to this extent.

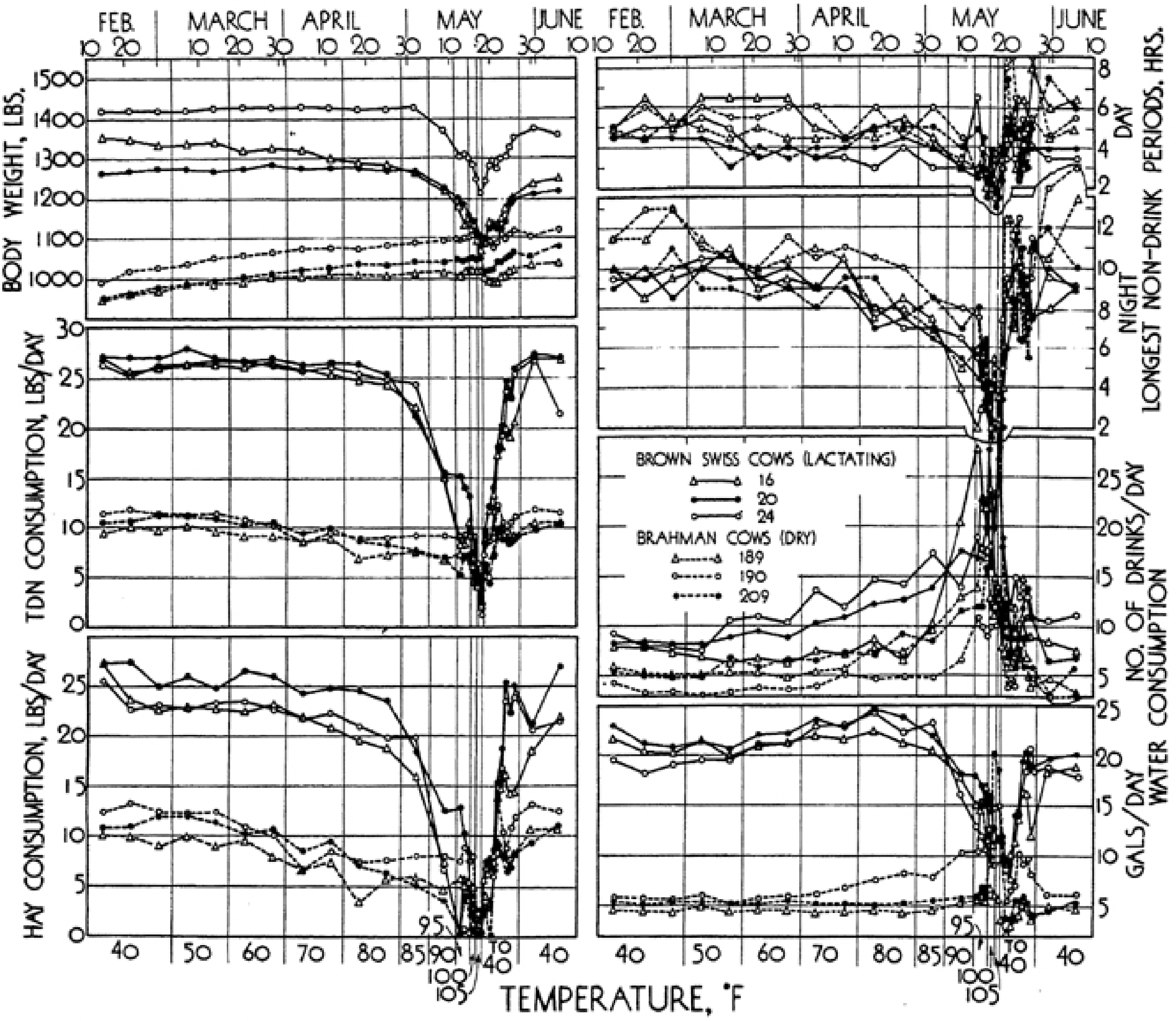

Fig. 4.—Curves showing the effect of increasing temperature on: hay and TDN consumption, body weight, total daily amount and frequency of water consumed, and the non-drink periods for lactating Brown Swiss cows (continuous lines) and dry Brahman cows (broken lines). Data points represent weekly averages up to and including the 90°F level, thereafter daily values are shown except for the last two weeks which are given as averages for the respective weeks.

Summarizing, beginning with the 85°F temperature level, the feed consumption declined more steeply with rising temperature than the milk production, so the animals lost weight. The efficiency of milk production (corrected for loss in body weight[4]), as well as the absolute yield, declined with rising temperature above 85°F.

Feed Consumption.—The left middle and bottom segments of Fig. 4

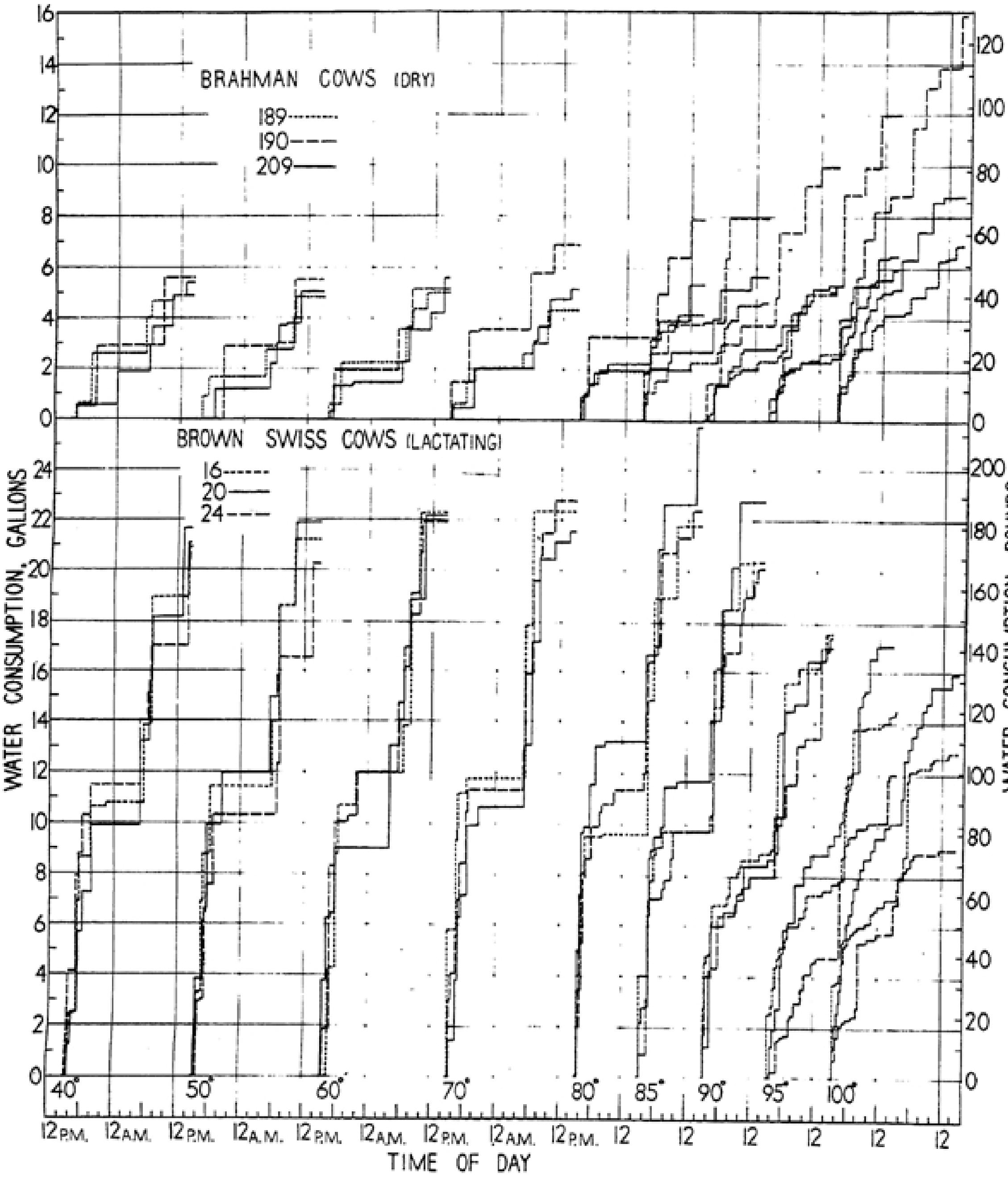

Fig. 5.—The effect of increasing temperature on the water consumption patterns of Brown Swiss cows (lower section) and Brahman cows (upper section). A twenty-four-hour period (3 p. m. to 3 p. m.) for each temperature level (40° to 100°F) is shown for each cow. The total water consumption for the twenty-four-hour period is represented by the height of the vertical line; the water consumption per drink is represented by the total height of each segment; the total number of drinks per day is represented by the number of vertical segments; the horizontal segments represent non-drinking intervals. Note how the non-drink periods (horizontal segments) become shorter with increasing temperature, and also the difference between the breeds. Approximate time of feeding was at 4:30 a. m. and 3:00 p. m.

(and Table 4) show that the Brahmans maintained their initial level of TDN consumption of about 10 lbs. per day. The Brown Swiss, on the other hand, began to decline rapidly in their feed consumption from about 27 lbs. TDN at 80°F, reaching a low of 2 lbs. at the 105°F. The decline in hay consumption began somewhat earlier as the hay was refused rather than the grain (the Brahmans received the same amount of grain throughout the experiment), but the temperatures at which the rapid decline began were about the same. All three Brown Swiss cows refused grain at both the 100 and 105°F levels; two Brahmans (189 and 209) refused grain at the 105°F level. Beet pulp was refused at the 105°F level by all cows except Brahman 190. The prompt return to the original feed consumption levels on lowering temperature was dramatic.

Body Weight.—The upper left segment in Fig. 4 and Table 4 shows that the body weight of the Brahmans was of the order of 1000 pounds and of the Brown Swiss 1300 to 1400 pounds; and, as previously noted (Res. Bul. 460), the Brahmans gained weight steadily, virtually unaffected by the rising temperatures until 100°F was reached. The lactating Brown Swiss lost weight first slowly, and when exposed to increasing temperature above 85°F very rapidly. The loss in body weight was no doubt accentuated by reduction in fill and complicated by changes in insensible loss and possibly changes in body composition.

Water Consumption.—The lower right section of Fig. 4 shows a curious difference in water consumption between the Brown Swiss and the Brahman cows. The lactating Brown Swiss consumed at 40 to 70°F about four times more water per day than the dry Brahmans. The Brahmans *increased* their water consumption above about 85°F whereas the Brown Swiss *decreased* their consumption beginning with 85°F. This *decline* in the water consumption by the Brown Swiss is presumably associated with their decline in milk production (milk contains about 77% water) and in feed consumption (which requires a lot of water); the *rise* in the Brahman water consumption may be associated with increasing evaporative cooling above 80°F, without decline in milk production (they were dry) or TDN consumption. The reaction of the Brown Swiss heifers to rising temperature in regards to water consumption will be shown presently and will throw more light on this subject.

There appears to be no substantial breed difference in the frequency of water drinking nor in the length of the non-drinking periods (upper right-hand charts in Fig. 4). Both breeds show an increase in the number of drinks per day with increasing temperature; and also a decline in the length of the non-drinking intervals, especially during the night.

Fig. 5 presents the water consumption data in the form of water consumption *patterns*, including: (1) amount of water consumed per day and per drink; (2) time of drinking; (3) duration of the non-drink intervals; (4) number of drinks per day. As reported in Res. Bul. 460, there are two relatively long non-drinking intervals, around midnight and noon, and that increasing temperature above about 85°F decreased the length of the non-drink periods and increased the drinking frequency. Numerical values of the total water consumed and the number of drinks are given in Table 5.

Heifers

Body Weight.—The top left-hand section in Fig. 6 shows virtually no breed difference, indeed no apparent effect of rising temperature on the body weight of the heifers. Body substance loss is, however, normally first compensated by body water gain, so that it takes some time for the body fat loss to register on the scales; and since the experimental intervals at the higher temperatures were very short, the shape of the body weight curve at the high temperatures is probably without substantial significance. Growth data obtained on Brown Swiss heifers at the Dannen Research Farm indicate that there was little difference in the rate of gain between the heifers we had under experimental conditions and those under customary farm conditions.

Feed Consumption.—The sections in Fig. 6 on hay and TDN consumption show a steady increase in feed consumption by these growing heifers of both breeds with advancing time and rising temperature up to 95°F, when the curves became flat, and at 100°F, when they rapidly declined. Numerical values are given in Table 6 of the appendix.

Water Consumption.—Both, the Brown Swiss and Brahman heifers, increased water consumption with increasing temperature; the increase was greater in the Brown Swiss than in the Brahmans (although Fig. 9 shows that the Brown Swiss spilled more water). There appears to be no breed difference in the frequency of drinking nor in the length of the non-drink periods. The number of drinks increased and the non-drink periods decreased with increasing temperature.

Change in Water Consumption with Rising Temperature as Affected by Age, Breed, and Milk Production

The most striking difference between the cows and heifers relates to water consumption, which *decreased* with rising temperature in the *milking* Brown Swiss cows and *increased* in their heifers. It was previously noted that while the *milking* Brown Swiss cows decreased, the non-milking Brahmans increased their water consumption with rising temperature; this difference was attributed to the decline in milk yield and feed consumption of the Brown Swiss cows with the associated decline in need for water consumption. The *increase* in water consumption with rising temperature in the *dry* Brown Swiss heifers and *decrease* in the *milking* Brown Swiss cows substantiates the idea that the decline in the lactating Brown Swiss cows was associated with the decline in milk production. There was no breed difference in water consumption in the heifers. It is, therefore, concluded that the decline in water consumption with rising temperature in the milking Brown Swiss is caused by their decline in milk production; and that if these Brown Swiss cows were dry, they would probably not have declined in water consumption with rising temperature.

Various aspects of water consumption with rising and declining temperatures for Holstein, Jersey, and Brahman cows were discussed in Res. Buls. 436, 449, and 461.

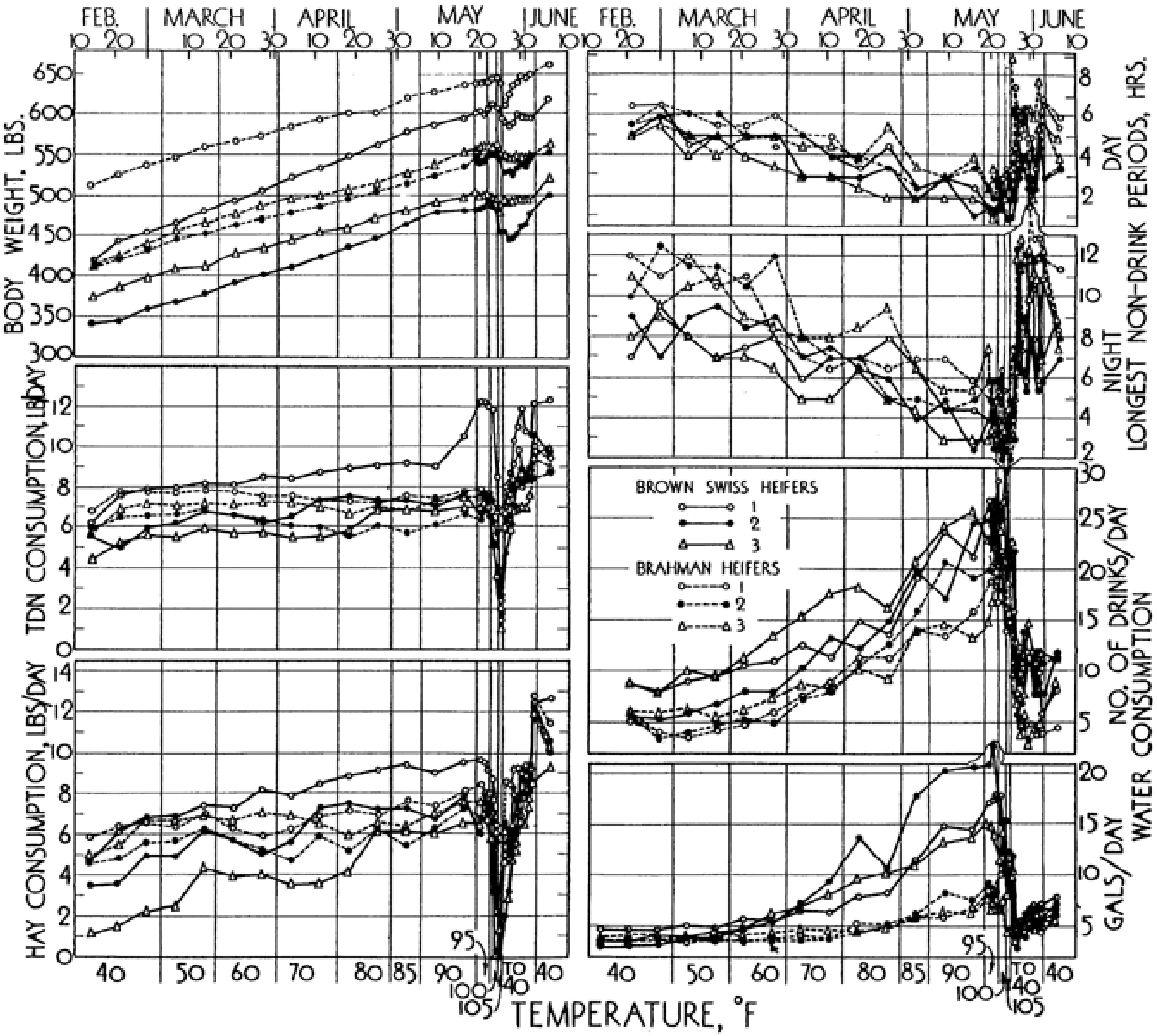

Fig. 6.—Curves showing the effect of increasing temperature on: hay and TDN consumption, body weight, total daily amount and frequency of water consumed, and the non-drink periods for Brown Swiss heifers (continuous lines) and Brahman heifers (broken lines). Data points represent weekly averages up to and including the 90°F level, thereafter daily values are shown except for the last week.

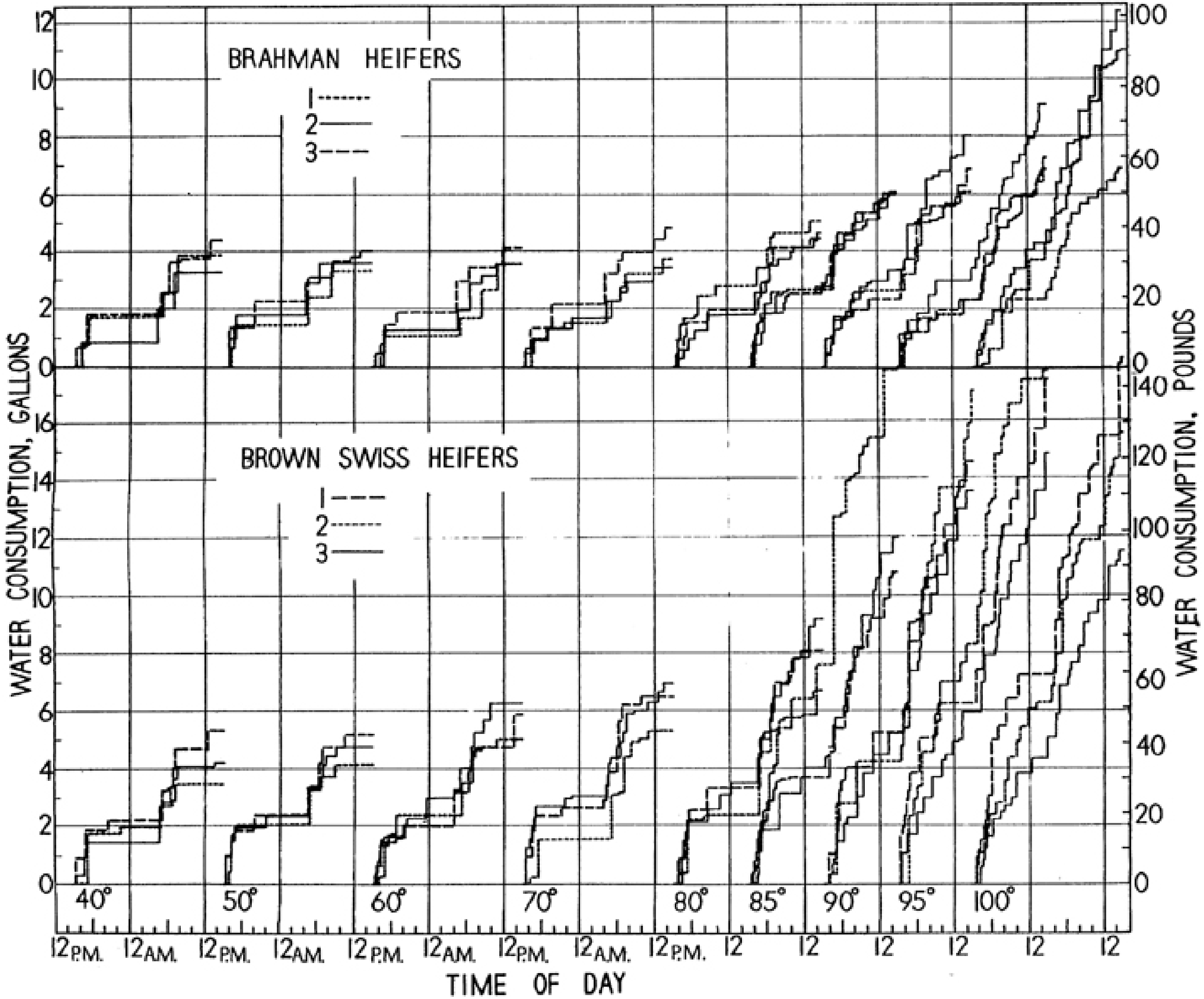

Fig. 7.—The effect of increasing temperature on the water consumption patterns of Brown Swiss (lower section) and Brahman heifers (upper section). A twenty-four-hour period (3 p. m. to 3 p. m.) for each temperature level is shown for each animal. See legend to Fig. 5 for further explanation.

There is an apparently systematic error in the water consumption data. The given water consumption data represent the total amount supplied to the water cups, including spillage from lapping and slobbering. The higher the temperature (above about 80°F) the more the animals tend to "play" with the cool water, licking its surface, dipping the muzzle into the cup then often throwing the dripping head over the back as if chasing flies. If one were to attribute purposive intent, or teleology, to cows, one would say that they sprinkled water over themselves the way, and for the same reason, that elephants do this in hot weather, to increase evaporative cooling; and that they forced the warmer water out of the drinking cups by their muzzle to let in the cooler water. Much of this lost water is spilled into the trough and soaked up by the dry hay. Fig. 9, showing the difference in the rejected hay before and after air drying, indicates in a *rough* way the increase in the amount of water that is used for non-drinking purposes with increasing temperature.

Summarizing, differences in the water consumption pattern above the critical temperature of about 80°F are not breed characteristics, but are mostly associated with differences in milk production. There may be exceptions to this general rule that water consumption in high milking cows tends to decline with increasing temperatures as illustrated by Jersey Cow 212 (discussed in detail in Res. Buls. 436 and 460).

ARE THERE BREED DIFFERENCES IN HEAT TOLERANCE?

Our data are too few and the choice of animals too restricted to justify frank breed comparisons. It may, however, be helpful to take stock of our preliminary comparative data.

Many factors are involved in heat tolerance; the most obvious of which are body weight, body form, feed consumption, and milk production. Some argue that for breed comparisons in heat tolerance all animals should be equalized with respect to these factors. But it is these factors that constitute breed differences, and if they were equalized, all animals would, for practical purposes, be of the same breed. If the animals were equalized for milk yield alone, one would have to choose a reference base for equalization—equalization per individual? per unit body weight? per unit surface area? per unit maintenance cost? per unit feed consumption? per unit invested capital? per unit of monetary profit or per overall dollar cost of milk production? At any rate it is not practicable for us to equalize all breeds with respect to milk production and body weight because we have no access to high-milking Brahman cows. The only breed equalization method available to us is to have all animals dry and in nutritional equilibrium (not gaining or losing weight on their customary feed). We have data on dry Brahman and Brown Swiss yearling heifers and also on dry Brahman cows; we next hope to secure data on dry Jersey cows. Comparisons of lactating animals of one breed with non-lactating animals of another breed is definitely not logical; nonetheless they may be edifying for purposes of orientation provided the reader is alerted to the involved dangers in misinterpretation.

With this introduction we present in Fig. 8, the breed comparison on milk and butterfat production, feed consumption, and body-weight responses to changing temperatures as we found them.

In Fig. 8 all curves are represented in terms of percentages of the levels at 50°F; that is, the values at 50°F equal 100 per cent. Data from Res. Bul. 460 for the 1949 (rather than the 1948) experiment were chosen for the comparison with the data presented in this bulletin because these two sets of data are more nearly comparable with regards to feed records (the hay was not cut nor air-dried before weighing back during the 1948 period).

The lower left quadrant in Fig. 8 presents a comparison of the curves on milk production with rising temperature of eight lactating cows (4 breeds). The Brahman cow showed the least decline in milk yield with rising temperature because her production was lowest at the beginning (the less the production the less sensitive the process to rising temperature) and because the tropically-evolved Brahmans may, perhaps, be more tolerant to high temperatures than are the European-evolved cattle. The Brown Swiss individuals used in this experiment held up somewhat better than the other individuals of European-evolved breeds used previously. The apparent superiority of these particular Brown Swiss individuals may, however, be due not to their greater heat tolerance as such, but perhaps to their having a higher lactational drive and higher persistence to overcome the thermal stress, and also to the fact that being on Register of Production Test they received somewhat more grain in proportion to milk yield than the other breeds. The subsequent reports in this series on the Brown Swiss, especially on rectal temperature, should answer additional questions concerning the relative heat tolerance of the several breeds.

The lower right quadrant in Fig. 8 similarly presents a comparison of the TDN consumption curves. The given Brahman (whether dry or lactating) held up feed consumption best—the temperature at which they began a rapid decline was about 10°F higher than for the other cows. The given Holstein cows appear to have the lowest critical temperature for TDN consumption. However, because of the relatively great errors involved in the feed consumption data and because of the criss-crossing of the curves, conclusions concerning breed differences in feed consumption are not justified at this time.

The upper right quadrant in Fig. 8 on body weight shows most dramatically the higher heat tolerance of the Brahmans over the other breeds. The Brahman gained weight steadily up to 100°F whereas the others lost weight; some began to lose weight at 80°F. The greatest body weight loss occurred in Brown Swiss 16, the highest milk producer; her weight loss reflected her high milk production combined with her depressed feed consumption.

The curves on butterfat percentage in the upper left quadrant show that the changes in the Jerseys and Brahman are much less than in the Holsteins

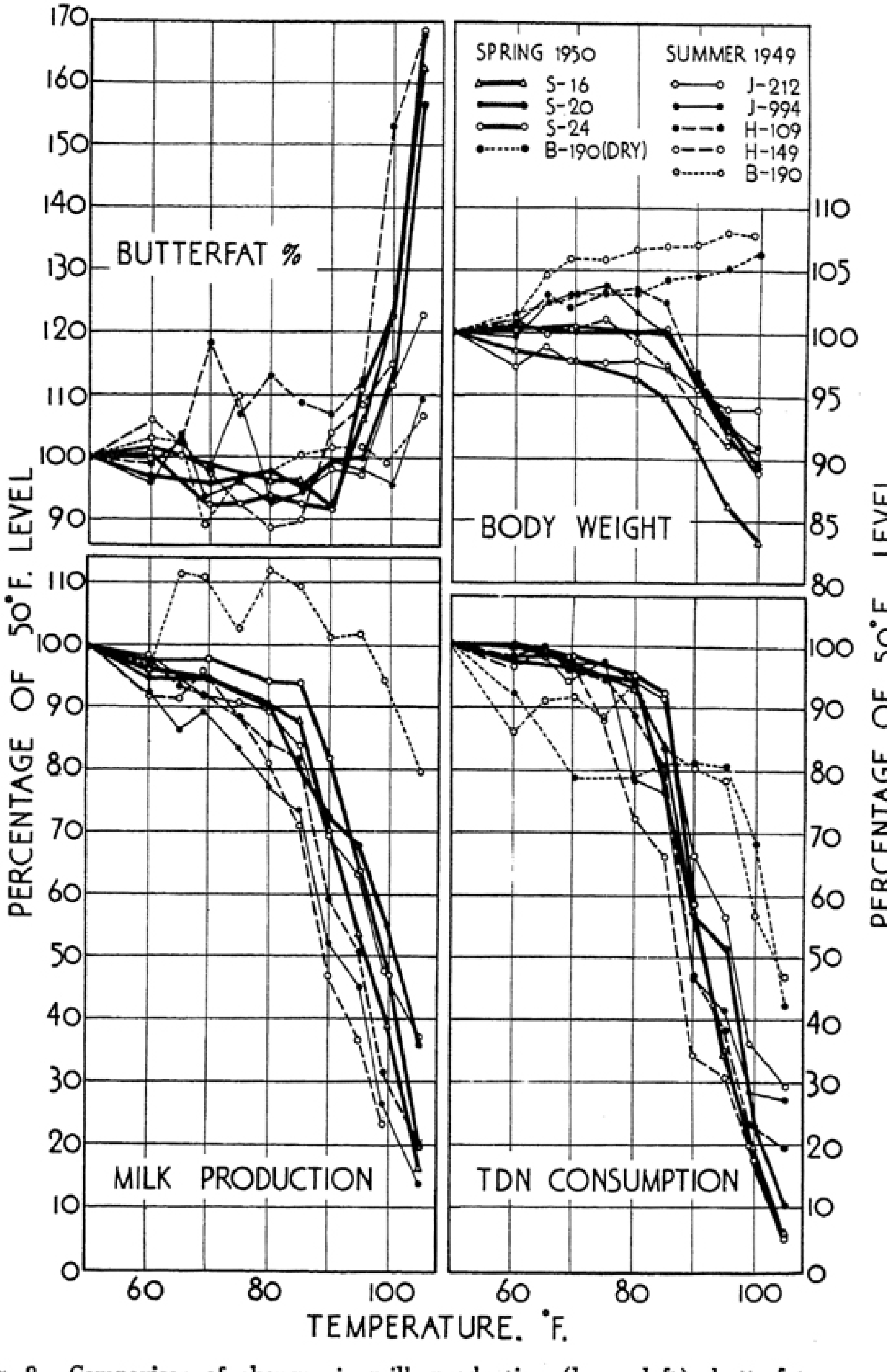

Fig. 8.—Comparison of changes in milk production (lower left), butterfat percentage (upper left), TDN consumption (lower right), and body weight (upper right) observed during the Spring 1950 and Summer 1949 periods on the four breeds of cows. "S" represents Brown Swiss cows, heavy continuous curves; "H" represents Holstein Cows, broken curves; "J" represents Jersey cows, light continuous curves; "B" represents Brahman cow 190—lactating during the Summer 1949 period and dry during the Spring 1950 period, dotted curves. Summer 1949 data from Res. Bul. 460.

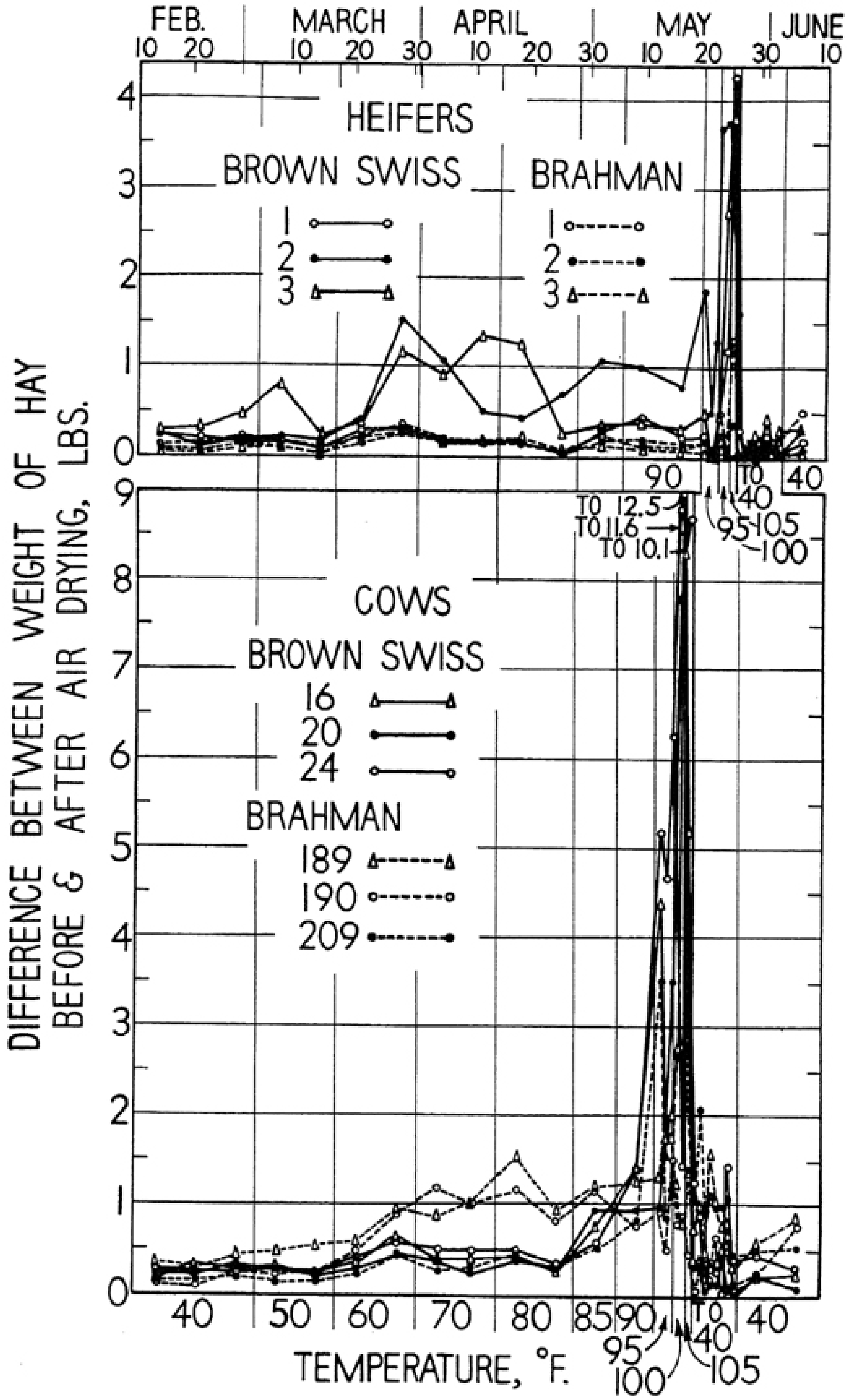

Fig. 9.—Water spillage by the animals into their mangers by slobbering and by lapping at the water increased with increasing temperature. Some of the water was taken up by the refused hay. The weight difference between the refused hay before and after air-drying provides a rough index of the amount of water spilled by the individual cows. Two Brown Swiss heifers appeared to have spilled more water than the Brahman heifers. Before 90°F Brahman cows 189 & 190 appeared to have spilled more than the Brown Swiss cows; above 90°F the Brown Swiss cows wasted considerably more than the Brahmans. The apparent water spillage may have been affected by the amount of rejected hay; the relation between these two was, however, too erratic for a definite conclusion.

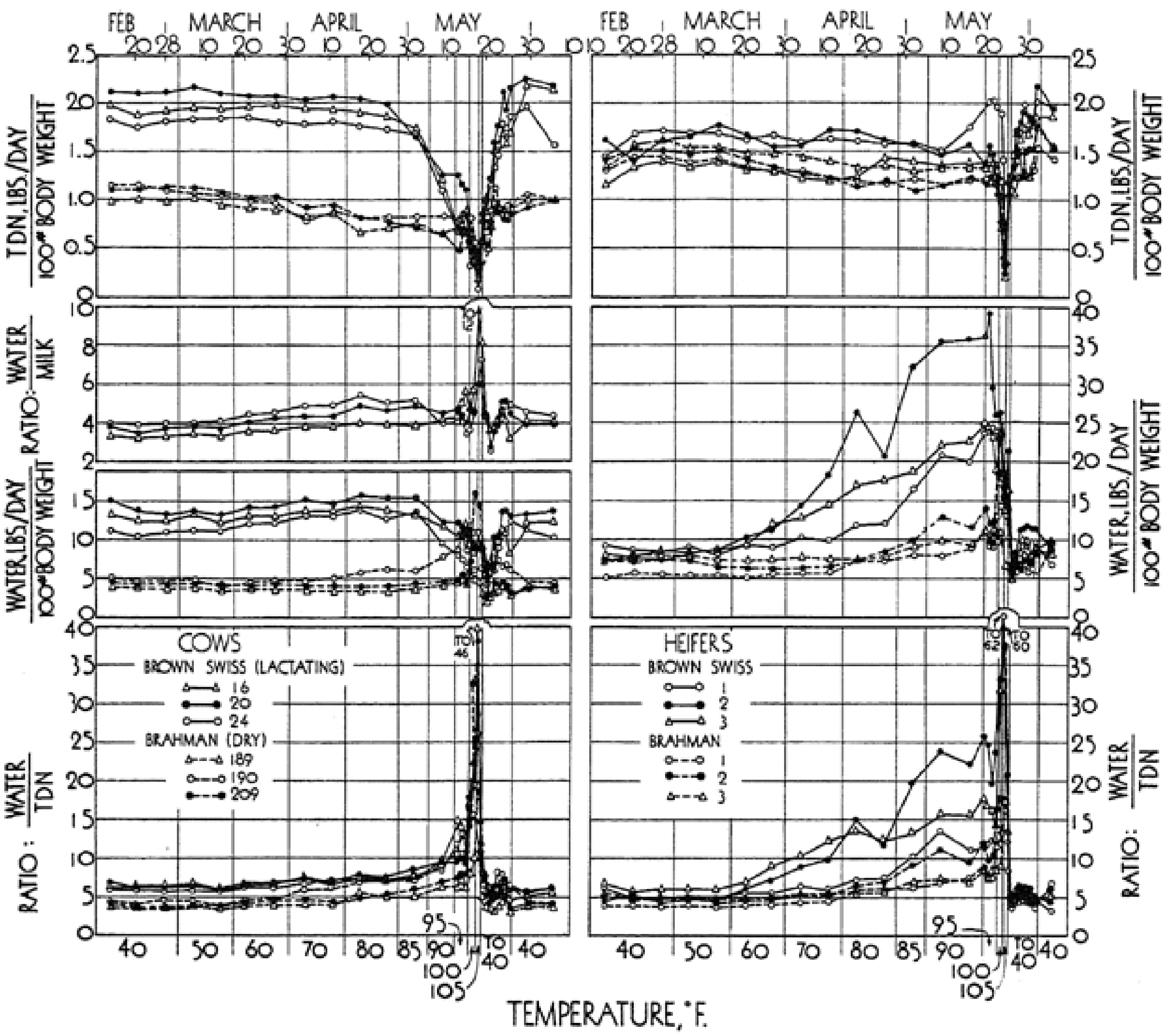

Fig. 10.—Ratio of TDN consumption to body weight, and of water consumption to TDN consumption, to body weight and to milk production. While the *absolute* water consumption *decreased* with increasing temperature in the heavily-milking Brown Swiss cows (Fig. 4), the ratios of water to feed and milk *increased* because of the greater decrease in milk and feed consumption than in water consumption. In the dry animals (Brahman cows and Brahman and Brown Swiss heifers) the absolute water consumption as well as the ratios increased with increasing temperature.

and Brown Swiss; that, indeed, the Holstein and Brown Swiss show a dramatic rise in fat percentages at the higher temperatures.

Summarizing, the one lactating Brahman cow held up milk production best with rising temperatures, perhaps, because she was the poorest milker; she did not have much to lose in her productivity. The Brown Swiss cows held up best, because, perhaps, they were the *best* milkers; their lactational drive may have been sufficient to overcome to a considerable extent the stressful conditions of rising temperature with the associated declining feed consumption. Opposite causes in these two breeds may have produced similar end results with regards to holding up the milk yield at the higher temperatures. More data on a variety of reactions are needed to clarify the situation. The Brahman held up feed consumption best, the Holsteins least. As aforenoted, the most dramatic breed difference in the cows is the way the Brahman gained weight throughout the entire period of rising temperature whereas the other cows lost weight; the greatest weight loss was observed in the highest milker—Brown Swiss 16. Here again the situation is confused because of the many factors that condition body weight change. For instance, there was no breed difference with regards to body weight in the Brown Swiss and Brahman heifers.

SUMMARY AND ABSTRACT

This is a progress report on the effect of rising temperature 40° to 105°F on feed and water consumption, body weight, and milk production in three high-milking 1300-1400-lb. Brown Swiss cows, three dry 1000-lb. Texas-bred Brahman (Indian evolved) cows, and six dry yearling heifers, daughters of these six cows.

The critical temperature in Brown Swiss cows for milk production, feed and water consumption, appears to be 85°F. Rising temperatures above 85°F depressed in the milking Brown Swiss cows the feed consumption more than the milk production, with consequent loss in body weight. The fat percentage increased with decreasing milk production. The non-milking Brahman cows showed less conspicuous and higher critical temperature for feed consumption and body weight. The *milking* Brown Swiss *cows* decreased and the *non-milking* Brahmans increased their water consumption with increasing temperature. Opposite effects on water consumption were observed in both the Brown Swiss and Brahman *heifers*. In brief, the water consumption tends to decrease with decreasing milk production during increasing temperatures.

While the Indian-evolved cows may be more heat tolerant than the European-evolved cows, no such breed differences were observed in the yearling heifers of the Brahman and Brown Swiss breeds.

APPENDIX

TABLE 3.--AVERAGE MILK AND BUTTERFAT PRODUCTION OF BROWN SWISS COWS AT THE VARIOUS TEMPERATURE LEVELS

Temperature Levels*, °F	BROWN SWISS		
	20	16	24
		Milk Production, lb/day	
40*	47.8	50.4	38.3
50	46.0	49.4	39.2
60	43.5	47.6	38.2
70	43.6	46.8	38.2
80	41.4	44.7	36.9
85	36.9	43.3	36.8
90	33.2	34.7	32.0
95	31.2	25.6	24.9
100	25.4	19.2	18.4
105	16.5	8.0	7.8
40**	41.1	38.1	31.6
		Butterfat, %	
40*	3.9	3.9	3.8
50	4.0	3.7	3.8
60	3.9	3.8	3.8
70	3.8	3.6	3.5
80	3.9	3.6	3.5
85	3.8	3.6	3.5
90	4.0	3.4	3.4
95	4.0	3.9	4.2
100	4.5	4.6	4.6
105	6.2	6.0	6.3
40**	3.9	3.8	3.8
		FCM, lb/day (Fat Corrected Milk to 4%)	
40*	47.1	49.4	37.0
50	45.8	47.2	37.7
60	42.5	45.8	36.8
70	42.3	44.4	35.0
80	40.8	41.7	34.1
85	35.8	40.4	33.8
90	33.0	31.8	29.4
95	31.2	25.2	25.5
100	27.3	20.8	19.9
105	22.1	10.4	10.5
40**	40.8	37.2	30.7

* Average for the two-week period, February 18 to March 3.
** Average for one-week period at end of experiment, June 3 to 9.

Approximate ratio of milk to grain was: 2.6 for 16 and 20 and 2.1 for 24 up to the 85°F temperature level after which time it increased to 4.6 for 16 and 24 and 4.1 for 20 at the 100°F level.

TABLE 4.--AVERAGE BODY WEIGHT AND FEED CONSUMPTION OF BROWN SWISS AND BRAHMAN COWS AT THE VARIOUS TEMPERATURE LEVELS

Temperature Level, °F	BROWN SWISS			BRAHMAN		
	20	16	24	209	189	190
Body Weight						
40*	1272	1341	1422	966	964	1022
50	1273	1338	1422	990	987	1045
60	1280	1321	1426	1008	997	1061
70	1276	1309	1428	1024	1009	1076
80	1273	1288	1422	1035	1008	1077
85	1270	1269	1426	1041	1016	1089
90	1228	1220	1370	1041	1017	1093
95	1183	1155	1306	1043	1018	1099
100	1138	1117	1266	1044	1022	1112
105	1107	1068	1217	1047	1020	1113
40**	1220	1252	1359	1075	1038	1120
Hay Consumption, lbs/day						
40*	26.2	23.2	22.9	11.4	9.4	12.8
50	25.4	22.8	23.0	11.6	9.5	12.2
60	26.3	22.8	23.0	10.5	8.6	10.5
70	24.5	21.4	22.0	9.0	7.0	7.5
80	24.1	19.2	20.4	6.6	4.5	7.5
85	18.5	15.9	19.9	5.0	5.9	8.0
90	12.6	7.4	6.6	3.5	4.7	8.0
95	10.5	3.7	.5	2.1	5.4	7.9
100	.4	1.1	.4	.2	3.0	5.1
105	.2	.1	.2	.8	.7	1.4
40**	27.0	22.0	21.5	11.0	11.7	12.5
TDN Consumption, lbs/day						
40*	27.1	25.9	25.7	10.9	9.9	11.6
50	27.6	26.4	26.5	11.0	9.9	11.3
60	26.9	26.4	26.5	10.4	9.1	10.5
70	26.5	25.7	26.0	9.7	8.7	9.0
80	26.0	24.6	25.2	8.5	7.1	9.0
85	21.3	22.2	24.4	7.7	7.6	9.2
90	15.6	15.1	15.4	7.0	6.8	9.2
95	14.2	9.2	9.2	6.2	7.2	9.2
100	6.3	5.2	4.7	5.3	6.0	7.8
105	2.8	1.6	1.3	4.1	2.5	4.8
40**	27.0	27.2	21.5	10.7	10.6	11.5
Grain Consumption, lbs/day						
40 to 80	17	18	18	5	5	5
85	14	17	17	5	5	5
90	10	13	14	5	5	5
95	10	8	10	5	5	5
100	6†	4†	4†	5	5	5
105	1.9†	0.2†	0.6†	3.2†	1.5†	3.5
40**	16	20	12	5	5	5

* Average for the two-week period, February 18 to March 3.
** Average for one-week period at end of experiment, June 3 to 9.
† Some grain refused.

TABLE 5.--AVERAGE FREQUENCY AND AMOUNT OF WATER CONSUMED BY BROWN SWISS AND BRAHMAN COWS AT THE VARIOUS TEMPERATURE LEVELS

Temperature Level, °F	BROWN SWISS			BRAHMAN		
	20	16	24	209	189	190
Water Consumption, gal/day						
40*	21.1	20.4	18.7	5.2	4.5	5.8
50	21.2	20.8	19.6	5.4	4.7	5.7
60	22.3	21.1	21.1	5.4	4.7	5.9
70	23.3	21.9	23.0	5.2	4.4	6.5
80	24.3	21.9	23.4	5.2	4.6	7.9
85	22.1	20.6	23.3	5.6	4.7	8.0
90	18.3	17.9	16.2	5.8	5.4	10.4
95	16.9	15.6	12.0	6.3	5.8	12.9
100	14.5	12.0	9.2	15.0	6.6	15.4
105	12.0	11.7	----	18.6	5.8	15.0
40**	20.4	19.0	16.9	5.5	4.8	6.2
Total Number of Drinks per day						
40*	8.4	7.8	8.1	5.0	5.3	3.5
50	8.6	6.7	9.1	5.9	5.4	3.2
60	9.3	6.6	10.7	6.3	5.1	3.8
70	10.7	7.5	12.8	7.4	5.7	4.6
80	12.6	7.8	14.5	8.2	7.8	4.9
85	14.0	10.4	17.4	8.6	9.9	4.9
90	17.7	20.6	14.0	11.7	13.1	6.6
95	20.0	24.3	19.0	13.3	16.3	10.0
100	24.0	19.5	15.0	19.5	12.0	10.0
105	27.0	14.0	----	28.0	13.0	11.0
40**	7.0	7.7	11.3	6.0	3.5	3.3

* Average for the two-week period, February 18 to March 3.
** Average for one-week period at end of experiment, June 3 to 9.

TABLE 6.--AVERAGE BODY WEIGHT AND FEED CONSUMPTION OF BROWN SWISS AND BRAHMAN HEIFERS AT THE VARIOUS TEMPERATURE LEVELS

Temperature Level, °F.	BROWN SWISS 2	BROWN SWISS 3	BROWN SWISS 1	BRAHMAN 2	BRAHMAN 3	BRAHMAN 1
			Body Weight, lbs.			
40*	354	391	447	426	432	532
50	374	414	473	449	460	552
60	396	430	500	467	481	570
70	419	448	527	483	498	588
80	441	466	555	501	511	602
85	464	481	578	514	527	618
90	479	493	591	530	546	633
95	487	500	604	544	560	640
100	484	498	611	549	562	645
105	454	477	596	546	550	638
40**	499	523	620	554	564	661
			Hay Consumption, lbs/day			
40*	4.2	1.8	6.4	5.2	6.0	6.5
50	5.5	3.4	7.1	5.9	6.8	6.6
60	5.3	3.9	7.7	5.4	6.8	6.0
70	6.4	3.5	8.1	5.3	6.6	6.5
80	7.3	5.1	9.0	5.7	6.2	7.0
85	7.3	6.1	9.4	5.4	6.3	7.7
90	7.3	6.3	9.3	6.8	7.3	7.7
95	7.1	6.7	9.5	7.2	7.5	8.1
100	1.7	2.9	5.5	6.1	6.9	6.8
105	0	0	0	1.1	1.2	0
40**	10.6	9.3	12.7	10.1	10.3	11.5
			TDN Consumption, lbs/day			
40*	5.5	5.4	7.7	6.5	6.9	7.7
50	6.5	5.7	8.1	6.7	7.1	7.8
60	6.4	5.7	8.4	6.5	7.2	7.5
70	7.0	5.5	8.6	6.1	7.1	7.4
80	7.4	6.3	9.0	5.8	6.9	7.3
85	7.4	6.8	9.2	5.7	6.9	7.6
90	7.4	6.9	9.8	6.4	7.4	7.6
95	7.3	7.1	12.3	6.6	7.5	7.8
100	4.6	5.2	10.3	6.0	7.2	7.1
105	1.9	1.1	1.5	2.8	2.1	2.2
40**	9.8	9.9	12.4	8.8	8.9	9.6
			Grain Consumption, lbs/day			
40 to 70	5	5	6	5	5	6
80 to 90	5	5	6	4	5	5
95 to 100	5	5	10	4	5	5
105	2.5†	1.5†	2†	3	2†	3†
40**	6	7	8	5	5	5

* Average for the two-week period, February 18 to March 3.
** Average for the one-week period, June 3 to 9, at end of experiment.
† Some grain refused.

TABLE 7.--AVERAGE FREQUENCY AND AMOUNT OF WATER CONSUMED BY BROWN SWISS AND BRAHMAN HEIFERS AT THE VARIOUS TEMPERATURE LEVELS

Temperature Level, °F	BROWN SWISS 2	BROWN SWISS 3	BROWN SWISS 1	BRAHMAN 2	BRAHMAN 3	BRAHMAN 1
			Water Consumption, gal/day			
40*	3.2	3.9	4.7	3.8	4.2	3.6
50	3.9	4.3	5.0	3.8	4.2	3.6
60	5.2	5.6	5.7	3.6	4.3	3.7
70	8.3	7.5	6.5	3.8	4.6	3.9
80	12.2	9.9	8.1	4.8	4.7	5.3
85	17.9	11.0	11.5	6.2	5.8	5.9
90	20.6	13.5	14.7	7.9	6.4	6.5
95	20.7	14.7	17.6	8.5	7.4	7.6
100	15.4	12.9	15.2	12.4	7.2	10.6
105	8.5	8.1	11.1	12.4	4.5	10.1
40**	6.7	5.6	7.8	5.3	6.3	5.3
			Total Number of Drinks per day			
40*	5.4	8.4	8.5	4.6	5.9	4.6
50	6.3	9.8	9.2	4.3	5.9	3.9
60	8.1	12.3	10.8	5.2	6.8	5.4
70	11.9	16.5	12.0	7.8	8.5	8.3
80	13.6	17.3	14.4	11.7	9.8	11.4
85	20.0	21.9	19.3	16.0	14.0	14.0
90	21.0	25.2	22.7	20.1	14.0	14.8
95	24.3	22.3	26.3	20.7	17.3	18.3
100	28.0	25.5	18.0	27.0	21.0	24.0
105	22.0	19.0	15.0	23.0	16.0	23.0
40**	12.0	11.7	8.4	11.7	9.0	4.6

* Average for the two-week period, February 18 to March 3.
** Average for one-week period at end of experiment, June 3 to 9.