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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XLVI. Comparison of the Effect of Environmental Temperature on Rabbits and Cattle. Part 2. Influence of Rising Environmental Temperature on the Physiological Reactions of Rabbits and Cattle

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SUMMARY

Though differing in detail, there are many overall similarities between cattle and rabbits in the physiological responses to rising environmental temperatures (48 to 110° F) as evidenced by:

(1) A meeting of the skin, hair, and air temperatures at approximately 105° F and with the rectal temperature at 106° F, indicating no heat loss by non-evaporative cooling.

(2) A rise in rectal temperature around 80° F with associated declines in feed consumption, heat production, and thyroid activity in both species.

(3) A remarkable similarity of the partition of surface and respiratory evaporative moisture loss.

(4) Both species having an explosive rise in respiration rate around 75° F. At 90° F to 100° F this increase is three-fold.

(5) The striking parallel curves (relative changes) in thyroid activity, heat production, and feed consumption at various environmental temperatures.

Major differences of the rabbit and cow are as follows:

(1) The relative changes in evaporative cooling with rising environmental temperature—particularly between 50° and 80° F. Cows greatly increased their surface loss between 50° and 80° F; rabbits did not. The rabbbits made their greatest increase in evaporative moisture loss above 85° F.

(2) The major relative difference is the absolute quantity of evaporative moisture loss of the two species.

(3) Differences in the amount of hair covering the body which obviously influenced the non-evaporative cooling as well as the evaporative cooling.

(4) The pulse rates were rather inconsistent in both species. Pulse rate in cows began to go up at 105° F whereas the rabbit's pulse showed an earlier increase at 80° F.

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INTRODUCTION

This is a continuation of University of Missouri Agricultural Experiment Station Research Bulletin 646 on the effect of environmental temperature on the growth responses and physiological reactions of rabbits and cattle. Literature concerning this subject was reviewed in the previous bulletin. Here, data will be presented on the effect of rising temperature on mature rabbits and cows while holding the other climatic conditions constant. Primary concerns were the physiological reactions associated with changing environmental temperature and the mechanisms involved in maintaining normal internal body temperature in face of changing environmental temperatures.

METHODS

Twenty mature New Zealand rabbits were used in this experiment. Half of them were raised at 48° F, the other half at 83° F. The rabbits were subjected to different environmental temperatures, increasing gradually from 48° to 110° F within a period of approximately three months.

The 48° F-reared rabbits were exposed to temperature levels of approximately 48°, 65°, 75°, 80°-86°, 90°, 92°-93.5°, 98°, 102°, 104°, and 110° F for 365, 28, 12, 21, 14, 7, 8, 3, 2, and 1 day, respectively. The 83° F-reared rabbits were exposed to similar environmental conditions with the exception that they were not exposed to the low 48° F temperature.

Data on rabbits obtained at each environmenal temperature level include: rectal, skin, and hair temperatures; total, respiratory, and surface vaporization; heat production; pulse rate; respiration rate; thyroid I^{131} activity; feed and water consumption; body weight; and urine and feces moisture loss. These data are

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*This research was conducted under the project leadership of the late Dr. Samuel Brody.

compared with those of mature cows (Brown Swiss, Holsteins, Jerseys, and Zebus) obtained under similar conditions.**

Methods similar to those used in the growth experiment in measuring the various physiological responses were employed here. Briefly, a 20 gauge copper-constantan thermocouple was used for the measurement of rectal, skin, and surface temperatures. Total insensible loss was measured by merely placing the rabbit in a cage and weighing the animal for an hour on a sensitive chainomatic balance (the precision is to one-thousandth of a gram). If any urination or feces (sensible moisture) occurred, the tests were repeated.

A "two-way" valve system was used in determining, gravimetrically, the respiratory moisture loss. The moisture of the inspired air was absorbed with a drierite. Expired moisture was absorbed in a similar drierite tube (8 inches long and 2 inches in diameter). Prior to and after a six-minute test time, the expiratory drier tubes were weighed on a chainomatic balance. The increase in weight or the amount of water absorbed in grams per unit time was determined, resulting in respiratory moisture loss per unit time.

Surface insensibie loss is determined by subtracting the respiratory moisture loss from the total insensible loss.

The closed-circuit mask with a three-inch diameter oxygen bell was used to determine the "resting metabolism" of the rabbits.

Respiration rates were taken by observing the flank movement. Pulse rates were determined by manual palpation.

The rabbits were fed *ad libitum* on a commercial rabbit pellet diet (Rockland Rabbit Feed, Arcady Farms Milling Company). Tap water and the feed were available from wall feeders. Daily feed and water measurements were made; water consumption data were corrected for evaporation losses. Salt spools were available at all times.

For each assay of thyroid activity 25 to 60μc (depending on size of animals) of I^{131} as carrier-free sodium radioiodine (NaI^{131}) was injected either into the marginal ear vein of the rabbit or intraperitoneally.

In vivo measurements of thyroid I^{131} content were made by holding a Geiger-Muller tube firmly on the neck skin of the rabbit over the regions (both lobes of thyroid gland) for maximum count rate.

A nuclear Chicago Rate Meter was used to indicate the counts per minute. The average maximum count rate was compared with that obtained from a known

**Cow data on rectal temperature, Mo. Agr. Exp. Sta. Res. Buls. 435, 464, and 473; on skin and hair temperatures, Mo. Agr. Exp. Sta. Res. Buls. 481 and 489; on total vaporization, Mo. Agr. Exp. Sta. Res. Buls. 451, 479, and 497; on surface and respiratory vaporization, Mo. Agr. Exp. Sta. Res. Buls. 479, and 497; on heat production, respiration rate, and pulse rate, Mo. Agr. Exp. Sta. Res. Buls. 435, 464, and 473; on milk production and TDN consumption, Mo. Agr. Exp. Sta. Res. Buls. 425, 460, and 471; on water consumption, Mo. Agr. Exp. Sta. Res. Buls. 436, 460, and 471; and on body weight, Mo. Agr. Exp. Sta. Res. Buls. 449 and 471.)

standard amount of I^{131} in a small glass vial and expressed as a percentage of dose. No factor was used for non-thyroidal I^{131}, as after 48 hours it tended to become negligible. During the assay the counts were made several times daily for about ten days. The decline in radioactivity of the gland, when plotted on semilog paper as percent of dose of I^{131} activity versus time, presents the exponential rate of release of thyroidal I^{131} hormone from the gland.

DATA

Rectal, Skin, and Hair Temperatures.

As the ambient temperature increased to above 75° F the rectal temperature of the rabbits began to rise (Fig. 1, upper left). Male rabbits reared at 48° F were very intolerant to heat (in comparison to the other rabbits) as evidenced by the steep rise in their rectal temperature at 75° F. The rectal temperature of the cows began to rise at about 70° F; however, the exact "critical temperature"*** depends on the breed and/or body size of the animal (approximately 70° F for the Holstein, 75° F to 80° F for Jerseys and Brown Swiss, and 95° F for Zebus). The critical temperature zones of rabbits and cattle were found to be similar, with the exception of the Zebu cattle.

Rectal temperatures of rabbits and cows were near the lethal limits at about 105° to 110° F environmental temperature. Rectal temperature of rabbits continued to be higher than that of the cattle at high environmental temperatures. Among the four breeds of cows, Zebus had the lowest rectal temperature in the temperature range of 40° to 110° F.

Skin temperatures of rabbits, cows, and man (Fig. 1, right) showed that man had a steeper slope than cows, and cows had a steeper slope than rabbits—the species order of their decreasing heat tolerance (Fig. 1, upper left).

The absolute differences in hair temperatures of rabbits and cows (Fig. 1, lower left) reflected the far greater insulation property of the rabbit fur, which apparently interfered greatly with heat loss. Generally, this non-evaporative cooling (based on temperature gradient of the animal) may be affected by many homeothermic mechanisms that compensate for the extreme experimental conditions, including changes in the rate of evaporative cooling and convective cooling by such factors as fur and skin thickness and body configuration.

Animal-air Temperature Gradients.

The temperature gradient (Fig. 2, top left) is, of course, dependent upon the rectal temperature level. The data showed, in the temperature range of 48°

***The term "critical temperature" here refers to a marked change in slope of a curve for a given reaction. For example, if the milk production curve for a given animal shows a marked decrease in slope after 80° F, this temperature is called the "Critical temperature" for the *given* animal.

to 110° F, that rabbits had the highest rectal-less-air temperature gradient, cows intermediary, and man had the lowest. At 105° F air temperature, the rectal temperature of rabbits was 2° to 3° F above, that of cows 1° to 2° F above, and that of man 6° F below the air temperature. This, incidentally, happens to be the order of these species' increasing heat tolerance as will be emphasized later.

Highest gradients (in the range of 48° to 110° F) between rectal and surface temperatures were found in the 48° F reared rabbits (Fig. 2, lower left), followed by the 83° F reared rabbits, then the large, productive European cows, and finally, the heat tolerant Zebus.

The rabbits' temperature gradient curve did not deviate from its downward linear course (from 48° to 110° F environmental temperature) as the cattle's did (Fig. 2, lower left). This may reflect the different levels of evaporative cooling at this temperature range.

The same story may be presented in another way. Figure 2 (lower right) shows that the sweating man had the greatest rectal-skin temperature gradient, with cows next, and rabbits the lowest.

Evaporative Cooling.

As the rising environmental temperature reduced the temperature gradient between the body and the environment in both rabbits and cattle, there was a consequent reduction in convective and radiative cooling and an increase in heat dissipation by evaporative cooling (Figs. 1, 2, and 3). Consequently, when the environmental temperature approached the body-surface temperature, the cooling by convective and radiative methods became nil—leaving vaporization as the only means for heat dissipation. Therefore, the ability to withstand high environmental temperatures is related to the ability to dissipate heat by vaporization.

Figures 3 (top) and 4 (upper left) compare the total evaporative cooling of rabbits, cows, and man. Cows showed a steep rise in evaporative cooling after 50° F, which appeared to level off around 85° F; evaporative cooling curves of man and rabbits did not show an increase until an environmental temperature of 85° F was reached. Above 85° F, man showed a dramatic exponential rise due to sweating and diffusion; whereas, in rabbits, evaporative cooling rose very slightly above 85° F and due, apparently, only to physical diffusion. This gives rise to two questions: Why were there such species differences? Were the sudomoter ("sweating") centers or cutaneous centers actuated at around 50° F in cattle as they were actuated in man at around 80° to 85° F?

Rabbits, like cattle, increased their surface and respiratory (lung) vaporization with rising environmental temperature (Fig. 3). It was somewhat surprising that, though cattle vaporized much more absolute moisture (total) than rabbits, the partitions of their moisture loss between the surface and respiratory were strikingly similar (Fig. 3, 3rd section). Similar results were obtained on rats and rabbits by various workers (Tennant, 1946; Hieroymi, 1931; and Kintner, 1956). Apparently, the water loss through the rabbit's or rat's skin is by diffusion. There is no question that cows have sweat glands, but whether they are functional (Findlay and Yang, 1948; and Dempsey, 1946) is debatable.

The ratio of surface to total vaporization in both rabbits and cattle increased with rising environmental temperature (Fig. 3) even though their respiration rates (Fig. 4, lower right) increased abruptly at about 70° F. This was partially due to the fact that the loss of moisture by salivation was included with the surface vaporization. Respiration rate (Fig. 4, lower right) appeared to be more shallow at high temperatures. Respiratory vaporization curves in both species had a higher critical temperature than outer surface or total vaporization (Fig. 3).

Physiological Adjustments.

The abrupt rise in the rectal temperatures of rabbits and cows (Fig. 1) coincided with their sudden declines in feed consumption, thyroid activity, and heat production (Fig. 5). These apparently were due to limitations in heat dissipation (Figs. 2, 3, and 4, upper left).

The declines in feed consumption, thyroid activity and resultant decline in heat production (Fig. 5) were efforts to reduce the thermal stress associated with higher metabolic levels.

The ratios of evaporative cooling to heat production (Fig. 4, lower left) indicate the ability of the various species to dissipate their body heat at varying environmental temperatures. This is a good estimation of the heat tolerance of the animal to high environmental temperature as evaporative cooling is the principal avenue of heat loss at higher temperatures.

Pulse rate (Fig. 4) may also indirectly reflect a homeothermic attempt to dissipate the body heat by increasing the surface temperature (for example, by circulating more blood in the periphery).

For studies concerned with the inconsistency of the heart rate and metabolism see Univ. Mo. Agr. Res. Bul. 646, 1957 and Meyer and Yost, 1939. The latter investigators observed a different response of heart rate and metabolism to thyroid injections into thyroidectomized rats. Apparently, the pulse is subjected to many controlling factors. For example, doses of thyroxine that elevated metabolism to normal only increased the heart rate to one-half of normal. But when using hydrolyzed split products of globulin (a cardio-stimulating compound) a more pronounced heart stimulation was obtained while the metabolism lagged behind (Meyer and Yost, 1939).

Or is the pulse change merely the effect of high temperature of the blood on heart rate? (The rectal temperatures in both species are higher, Fig. 1.) Other intriguing questions are: What are the differences in pulse response to high temperatures between the rabbits and cows? Will the possible loss of rumen function at high temperatures influence the pulse?

The pulse rate (Fig. 4), which many workers believe varies directly with metabolism, did so with the cows. However, the pulse rate of rabbits did not vary directly with the metabolism.

Associated with these changes are the dramatic declines in productive processes above 75°-80° F in cattle and rabbits. More specifically, the critical temperatures for the aforementioned physiological reactions which are associated with heat production of rabbits and cows are as follows: For feed consumption, thyroid activity, and heat production around 75° F for the rabbits and around 80° F for the cattle (Fig. 5).

Relative rates of decline of these three functions are strikingly similar, especially in the rabbits. The thyroid activity (Fig. 5) showed a dramatic decline in the rabbits and cows around 80° F. This may be due to other endocrine interactions, such as the influence of cortisone or other adrenal cortical secretion on thyroid activity, since Myant (1953) believed that cortisone acted as exogenous thyroxine by reducing the 24-hour up-take as well as the rate of release of hormone I^{131} from the rabbit thyroid gland. Also, Brown-Grant *et al.* (1954) had shown cortisone depressed thyroid release rate in rabbits. However, this sudden drop may not necessarily be due to a direct effect of temperature on the neuro-endocrine system as indicated by Uotila (1940) but was likely due indirectly to a resultant cessation of feed intake (Fig. 5, lower left). Therefore, feed consumption as well as thyroid activity may be considered a process that contributes to heat production—the feed directly and the thyroid hormone indirectly as a metabolic catalyst. Heat production (Fig. 5) did not decline dramatically above 80° F since there was a certain basic level of metabolism essential for life.

Metabolism in rabbits appeared to increase slightly at around 100° F due to the higher body temperature. This is in accordance with van't Hoff Arrhenius law. When the body temperatures began to increase (even less than 1° F) these processes were affected immediately (Figs. 1 and 5). The controlling centers for feed intake are in the hypothalamus (Brobeck, 1948) and for thyroid secretion rate in the pituitary gland.

Feed and Water Consumption.

A further consideration of feed consumption indicates that the animal's desire to eat (Fig. 5, lower left) diminished rapidly above 75° F in the rabbits, and around 80° F in the European cattle. The more heat tolerant Zebu cattle continued their initially low level of feed consumption until 95° F when their appetite was also depressed by a rising body temperature.

The decline in feed consumption led to a loss of body weight (Fig. 6). As the feed or TDN consumption of rabbits and cows declined at about 80° F, a similar relative change should occur in the metabolism from the thermodynamic viewpoint. However, this decrease was not as great for the metabolism (Fig. 4, upper section) and therefore body tissues were metabolized as evidenced by the loss in body weight. This is further evidenced by the relationship of heat production to feed consumption. Around 100° F the feed consumption decreased drastically to a very small amount, whereas the decrease in heat production was relatively slight.

Some dramatic individual differences in water consumption (Fig. 6) were observed. For example, water consumption of lactating Jersey cow 212 increased fourfold on increasing ambient temperature from 50° to 100° F. Other lactating cows only increased their water consumption slightly (Fig. 6) while dry cattle as well as dry rabbits reduced their water consumption.

It is generally assumed that there is a strong correlation between feed and water at normal temperatures. However, Fig. 6 indicated that this is not true in rabbits and cattle at higher environmental temperatures.

There was a very dramatic rise and a strong similarity of the ratio of water consumption to feed or TDN consumption of rabbits and cows with increasing environmental temperature (Fig. 6). These data indicate the great decrease in feed consumption and little change in water consumption with rising temperature (Fig. 6, left section). These animals are endowed with an appetite center which decreases their feed consumption to minimize the heat increment of feeding above 75° to 80° F ambient temperature. But in the case of rabbits a question arises: Why did they decrease their water consumption at higher environmental temperatures, even though they vaporized more from the body.

Ratios of Physiological or Homeothermic Functions.

The reactions of the various physiological functions to rising environmental temperatures have been presented. The following ratios are presented for a better understanding and interpretation of these reactions and their interrelationships, and to summarize some of these various functions (Figs. 7 and 8).

The relative rates of increase of the ratio of respiratory vaporization to heat production (Fig. 7, upper section) indicated a similar response in rabbits and cows. Thus there is evidence of similarity in pulmonary response.

However, the relative rates of surface vaporization (the heat production) change less (Fig. 3) in the cow than in the rabbit, particularly between 50° and 80° F. This is one of the major differences of the cow and the rabbit. Note that between 60° and 80° F the ratio of the cow increased some 3 percent and that of the rabbit 4 percent per 1° F increase in environmental temperature.

The lower section of Fig. 7 reflects another minor difference of the rabbit and the cow. The rabbit increased the ratio of total vaporization to water consumption from around 40 percent at 80° F to about 125 percent at 110° F. Since the water loss at 110° F was primarily by vaporization (Fig. 3) it was assumed that the heat intolerant rabbit was becoming dehydrated even though it had plenty of water available to drink.

The cow's ratio did not increase so much above 80° F because cows tended to increase their water consumption, with a resultant lower ratio of total vaporization to water consumption than the rabbit (Figs. 3 and 7).

Differences in the relative rate changes between 50° and 80° F of the rabbit and cow (Fig. 7) were due to dramatic rise between 50° and 80° F of the evaporative cooling rate of the cow and little change in the rabbit.

From a discussion of the relation of evaporative loss to various physiological functions, we turn now to some of the interrelationships of other homeothermic mechanisms at increasing environmental temperatures (Fig. 8, upper section). In a comparison of the ratio of respirations per minute to pulse rate per minute of cows to that of the rabbit, it was found that cows had a much steeper slope, indicating either a greater respiratory response to temperature or less increase in pulse rate (Fig. 3). There was not too great a difference in the respiratory response of rabbits and cows, although the rabbit's pulse tended to increase at higher temperatures which may indicate the vasomotor response of the rabbit to higher environmental temperature. The more heat tolerant animals, such as the Zebu, and the 83° F reared rabbits showed a lower respiration rate. This probably was due to their lower body temperature.

Relative rates of the ratio of heat production to pulse indicate the general similarity of metabolism and pulse of the rabbits and cows, though there were minor differences.

The ratios of respirations to heat production (Fig. 8) also emphasized the similarity of the responses of these two reactions (Fig. 3) of rabbits and cows to rising environmental temperatures.

The major difference in the absolute values of the ratio of respiration rate to rectal temperature of rabbits and cattle was due to the higher respiration rate of the rabbits. However, the relative rates of increase of the ratio of the two species were identical. This further emphasized a strong similarity of behavior of the rabbit and cow to rising environmental temperature.

Heat Tolerance.

The many physiological reactions of these two species, some associated with heat production and others associated with heat dissipation, have been discussed. How can high productivity be maintained during seasons when high temperatures are depressing the productive processes, such as milk production, due to homeothermic adjustments in feed consumption, metabolism, and thyroid activity?

One possible answer may be to develop (by breeding and selection) animals that possess a greater tolerance to high temperatures—a greater ability to dissipate their heat increments associated with high production.

At the high environmental temperatures (80° F and above) apparently the most effective means of cooling an animal is by evaporative cooling. The data indicate this is true but leave us with the paradox that the evaporative cooling per animal is relatively greater in cows than in the sweating man (Fig. 3). Fig. 2 shows the cow to be highest, man next, and rabbits lowest in absolute amounts of evaporative cooling per animal. Apparently this is largely a reflection of the difference in sizes. Perhaps the answer is that the ratio of evaporative cooling to heat production is a better measure of heat tolerance (Fig. 3), still, when figured in this manner the cows have the highest absolute value, man intermediate, and the rabbits lowest.

Rectal temperature data (Fig. 1, left section) indicate that man is the most heat tolerant species. Both rabbits and cows were similarly intolerant to temperatures above 80° F, whereas man showed practically no rise in body temperature, even at 100° F.

By observing the chart more closely (Fig. 3, left) and noting the relative rate of rise in the ratio of evaporative cooling to heat production, especially above 80° F, it was found that man showed the greatest responses (a greater relative increase of evaporative cooling over heat production), cows intermediary and rabbits least. Since equal slopes (k) on semi-log grid represent equal percentage changes in Figure 4, the increase in the ratio of evaporative cooling to heat production for man above 80° F is about 10 percent, for cow about 2 percent, and for rabbit about 4 percent for each 1° F increase in environmental temperature. The data also show an increase of approximately two-fold in evaporative cooling in the cow ratio between 50° and 80° F. What type of cutaneous stimulation may be occurring within the cow so that it differs from the other two species?

By studying these values at 100° F to 105° F environmental temperature, (Fig. 3) it was found that man could vaporize about 150 percent of his estimated heat production to the environment (including some absorbed from the environment), European cows around 100 percent, Zebus 120 percent, and the rabbit only around 30 percent. Thus these heat tolerance ratios are directly related to the species body temperature response to rising environmental temperatures (Fig. 2), which ranks them in their position of heat tolerance. However, it is likely that rabbits, due to their larger ears and greater surface per unit weight, may lose proportionally more of their heat by non-evaporative cooling. Being very heat intolerant, many of the rabbits began to die after a few days exposure at about 100° F.

DISCUSSION

The constancy of the internal environment is one of the most characteristic features of all warm blooded living beings. This constancy is maintained until extreme environmental conditions are confronted or when a disfunction of a important organ in the body occurs. In this study the main concern has been on one of the many homeostatic characteristics of these animals—a constant body temperature—and the mechanisms for maintaining its constancy in these species.

The responses of rabbits and cows to rising environmental temperature above 50° F were generally as follows: As the temperature gradient between the animal and its environment decreased with increasing environmental temperature, certain compensatory mechanisms were activated. These various processes, such as respiration rate and evaporative cooling, increased their rate of function of response in an attempt to maintain normal body temperature. As the air temperature continued to increase (temperature gradient decreased further) it became increasingly difficult for these animals to dissipate their heat by non-evaporative measures and the body temperature began to rise. Even when the body temperature increased only 1° F, the many processes associated with heat production, such as milk production, or work, thyroid secretion rate, metabolic rate, and feed consumption began to decrease.

Possible Mechanisms of Interaction of These Physiological Responses.

On the basis of data presented it is apparent that many endocrine functions and metabolic processes are similarly involved or interrelated in the rabbit or cow.

For example, what is the influence of the thyroid hormone on metabolism in these species? The thyroid or other hormones do not initiate or halt any metabolic reactions, but simply modify the rates of the existing ones. This may be by influencing the enzyme activity directly or by modifying the cell permeability to specific substances. Perhaps the thyroid hormone acts as a cell stimulant through cytochrone C (Drabkin, 1950).

The heat production data are an *in vivo* manifestation of the general enzyme, endocrine, and biochemical functions or activity at the cellular level. A considerable amount of *in vitro* work substantiates this (Kunkel and Campbell, 1952). At the cellular level the metabolism of carbohydrate, primarily an immediate source of energy for work and synthetic process, generates energy during glycolysis by the way of Krebs citric acid cycle in which the oxidation of the carbon chain is carried to completion (CO_2 and H_2O).

The decline in feed consumption at high temperatures, of course, provides less exogenous substrate for the cells to metabolize. If the metabolism remains high (as in case of fever or extremely high environmental temperatures, Fig. 4) then body tissue is the source of substrate and is rapidly metabolized.

However, all of these considerations do not tell us the mechanism of action. Which is the cause and which is the effect?

Possible Mechanisms of Action.

One view is that as the environmental temperature rises, the feed intake is the first of the mechanisms mentioned above (in both rabbit and cow) to decline (Fig. 5) when the body temperature starts to rise (Fig. 1). This appetite decline may be due to a direct effect of temperature on the hypothalamus "appetite center" (Brobeck, 1948). It results in a lower feed consumption and thus a lower level of heat production. The lower metabolism requires less thyroid hormone since less of the hormone is being used in cell metabolism. Thus the higher blood level (Rand, *et al.* 1952) of the unused hormone depresses the pituitary and therefore reduces the thyroid secretion rate. Furthermore, von Euler and Holmgren (1956) found, by injection of thyroxine into various regions of the lower portion of the brain, that it was the region of the anterior pituitary in which thyroxine inhibited the release of I^{131} from the thyroid gland.

Many believe that it is the blood concentration of the hormone which governs the secretion rate of the gland (thyroid, adrenal, gonadal, etc.) and Rand *et al.* (1952) believed that it was the tissue demand which varied the level of the concentration in the blood. Theoretically, from these views, the blood level of the hormones will remain constant until a gland is exhausted or severely depressed for a number of reasons (extreme environmental temperature, sickness, etc.). And the metabolic level of the cells or tissues actually controls the thyroid activity.

Another similar view gives the level of the tissue metabolism a more important role in activating the thyroid gland. Greer (1952) has shown that destruction of the para ventricular nucleus (area of hypothalamus) causes a loss of thyrotropic hormone release by the pituitary. This suggests the mediation of the central nervous system in thyroid activation and also indicates that the origin of the demand for greater thyroid activity lies in the soma.

A third view is that the thyroid is depressed directly by temperature via the central nervous system, pituitary (Uotila 1940).

General Considerations.

Due to the very complicated balance between physiological and/or neuroendocrine reactions associated with both heat production and heat dissipation, perhaps the net effect should be discussed—in relation to the relative effects of rising environmental temperature on rabbits and cattle. Also, both heat production and heat dissipation mechanisms should receive equal consideration, partly because they cannot be studied separately and partly because it is believed the ratio of evaporative cooling to heat production is a valid measure of heat tolerance of animals(Brody, 1956, and this publication, Fig. 4).

The heat or cold tolerance of animal may be measured by its physical or physiological ability to maintain its body temperature constant in face of extreme environmental conditions. (See Figure 1.) However, in considering all the data presented and particularly the ratio of evaporative cooling/heat production, the only way to increase heat production and maintain high productivity at high temperatures is to increase the evaporative cooling potential of the animal, and/or obtain a greater efficiency in conversion of feed energy to metabolizable energy. That is, keep the body temperature at a near normal level so as not to stimulate homeothermic mechanisms, such as decreases in feed consumption, heat production, and the thyroid activity, which lower the productivity of the animal.

Thus, the immediate goal of animal climatologists is to explore further the details of all possible mechanisms of heat dissipation and heat production. They need to investigate physical and physiological characteristics that will increase the efficiency of the heat dissipation mechanisms as well as heat production to provide basic indices for further breeding and selection. A search for more efficient hot weather feeds (a lower specific dynamic action) or dairy animals that may be more efficient in converting feed energy (Lyon, 1953) to milk may be of great value. In this respect the rabbit may someday be very important in basic climatic studies or studies of the efficiency of feed conversion, heat increments of feeding, etc. Its fermentation vat is on the other end of the digestive tract as contrasted to the cow, which offers an opporunity for unique and critical experiments.

CONCLUSIONS

There are many similarities of cattle and rabbits in their feeding habits, nutritional behavior, and reactions to environmental temperature.

Both rabbits and European cattle behaved like arctic evolved species by making better growth gains in the colder (48° to 50° F) environment.

The similarity in growth response of rabbits to that of European cattle makes the rabbit particularly valuable as a pilot-experimental animal for economical reasons: 1) the rabbit is a relatively inexpensive experimental animal, and 2) it has a much shorter life span which allows an investigator to obtain much growth and related information in a relatively short period of time.

Rabbits generally were not quite as tolerant as cattle to rising environmental temperature as evidenced particularly by the much lower ratio of evaporative cooling to heat production at around 100° F.

However, the minor differences between the two species are mainly physical and physiological adaptations to the environment. Knowledge on such differences are very beneficial to environmental physiologists in the sense that they contribute much basic information to some of the intricate mechanisms of heat production and dissipation.

Results from these comparative studies indicate that the rabbit is a valuable pilot animal for bioclimatic studies on cattle.

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APPENDIX

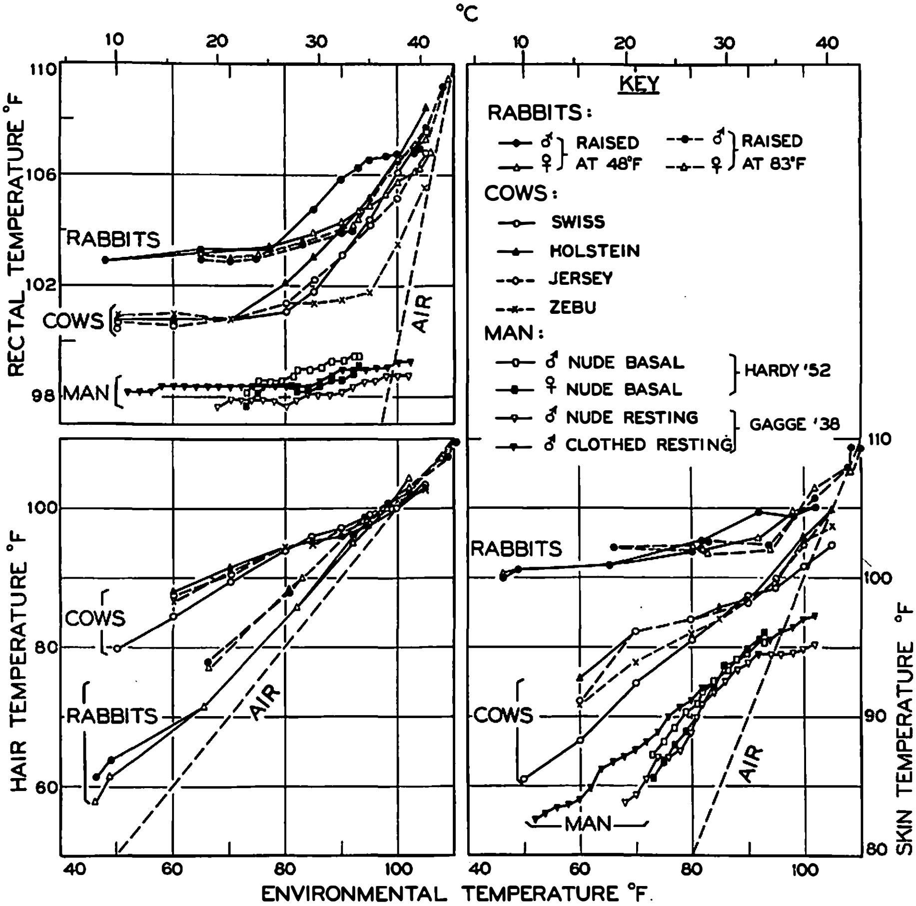

Figure 1. Rectal, skin, and hair temperatures of rabbit, cow, and man at various environmental temperatures. (Cow data on rectal temperature, Mo. Agr. Exp. Sta. Res. Buls. 435, 464, and 473; on skin and hair temperatures, Mo. Agr. Exp. Sta. Res. Buls. 481 and 489. Man data on rectal and skin temperatures DuBois, E. F., Ebaugh, F. G., Jr., and Hardy, J. D. J. Nutr. 48:257, 1952; and Gagge, A. P., Winslow, C-E. A., and Herrington, L. P., Am. J. Physiol. 124:30, 1938).

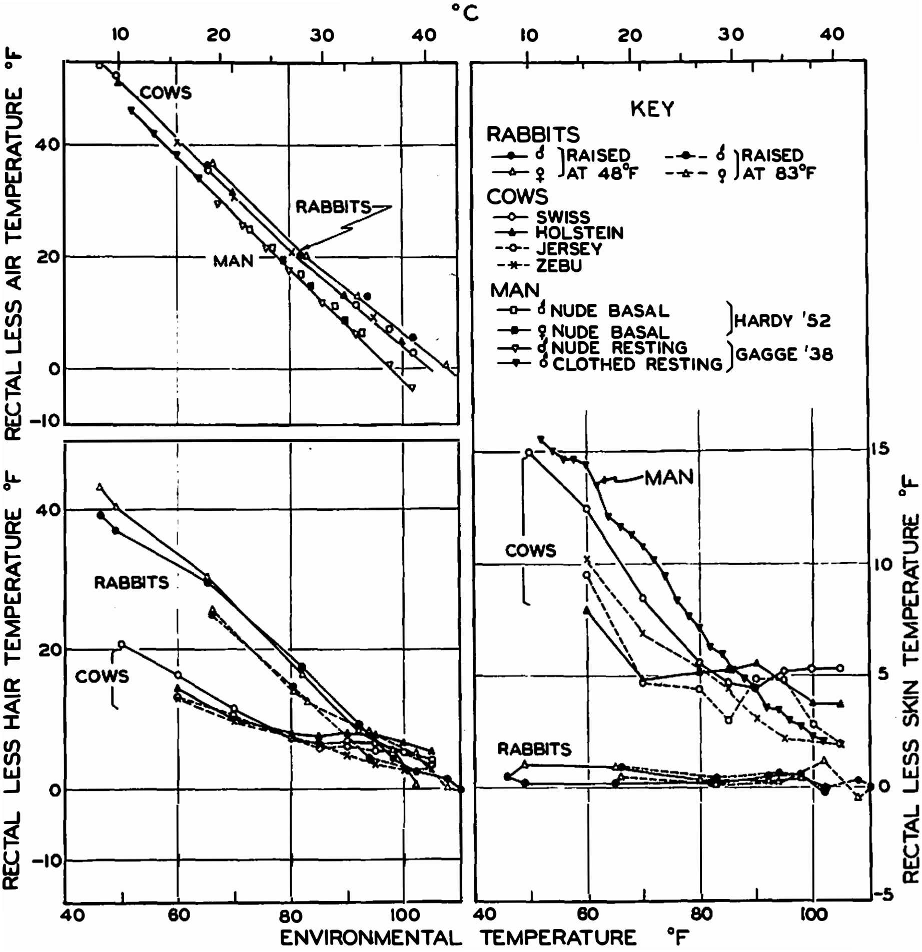

Figure 2. Temperature gradients between the animal and its environment. (Sources of cow and man data, same as Figure 1).

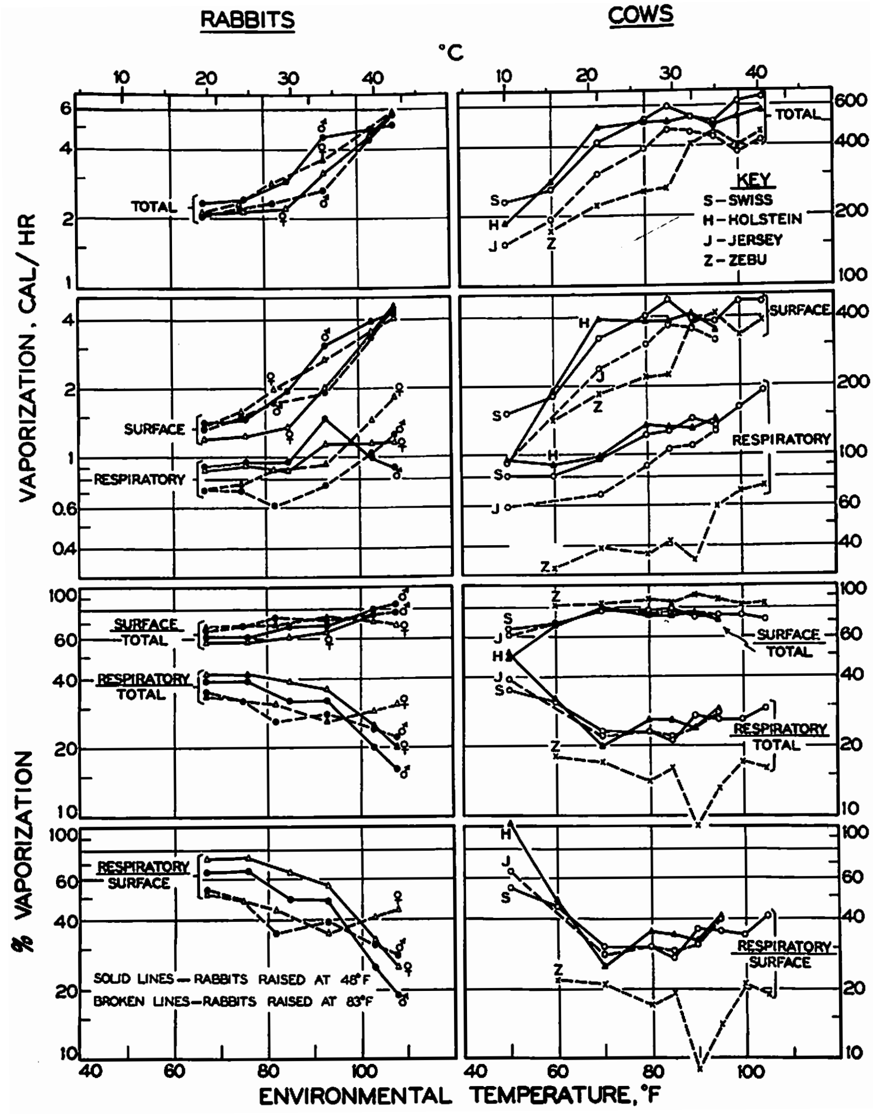

Figure 3. Total, surface, and respiratory vaporization of rabbits and cows and the ratios of surface to total vaporization, respiratory to total vaporization at various environmental temperatures. (Cow data on total vaporization, Mo. Agr. Exp. Sta. Res. Buls. 451, 479, and 497; and on surface and respiratory vaporization,, Mo. Agr. Sta. Res. Buls. 479 and 497).

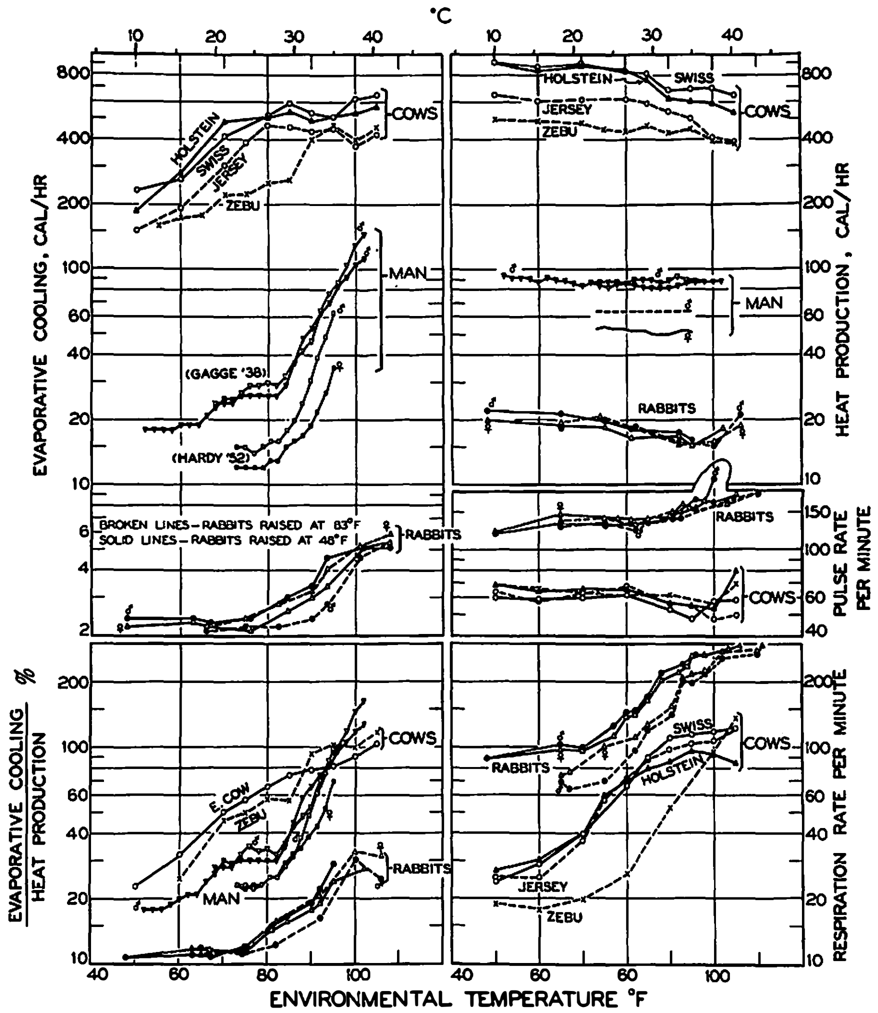

Figure 4. Comparison of evaporative cooling, heat production, pulse rate, and respiration rate in rabbits and cows. (Cow data on evaporative cooling, Mo. Agr. Exp. Sta. Res. Buls. 451, 479, and 497; and on heat production respiration rate, and pulse rate, Mo. Agr. Exp. Sta. Res. Buls. 435, 464, and 473).

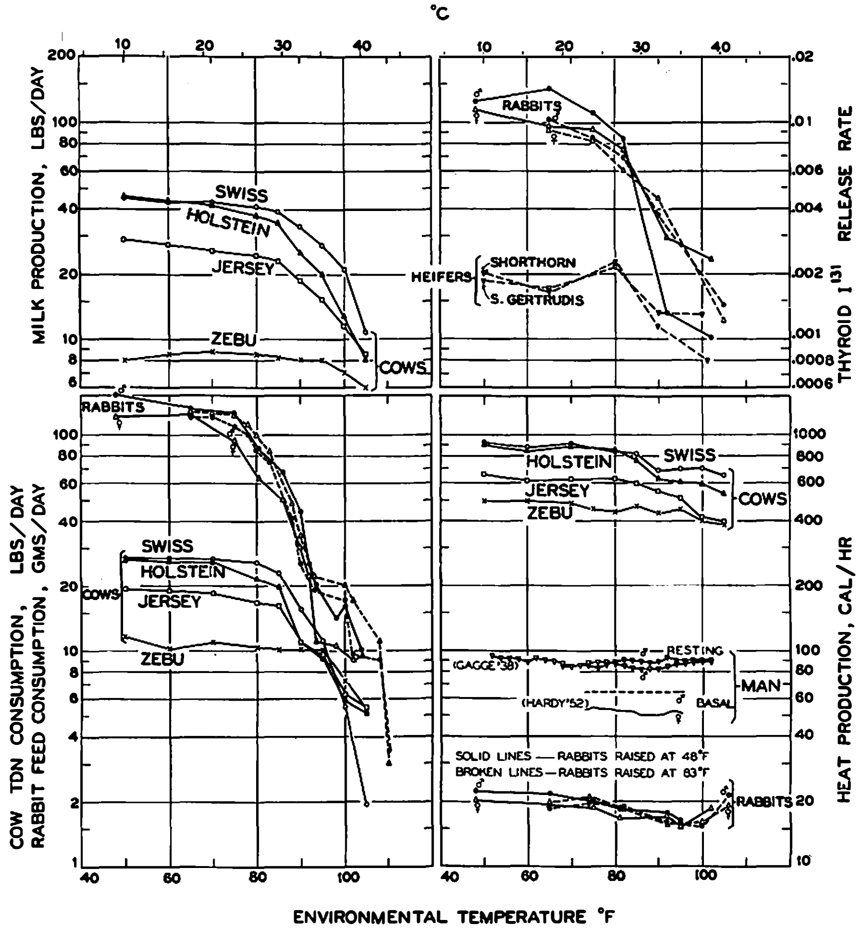

Figure 5. Milk production, feed or TDN consumption, thyroid I^{131} release rate and heat production of rabbits and cows at various environmental temperatures. Note that thyroid data of heifers (Santa Gertrudis, Zebus, and Shorthorns) were used due to lack of *in vivo* data on mature cows. (Cow data on milk production and TDN consumption, Mo. Agr. Exp. Sta. Res. Buls. 425, 460, and 471; and on heat production, same as Figure 4. Thyroid data of heifers, from Blincoe, C. R., Unpublished data, 1956).

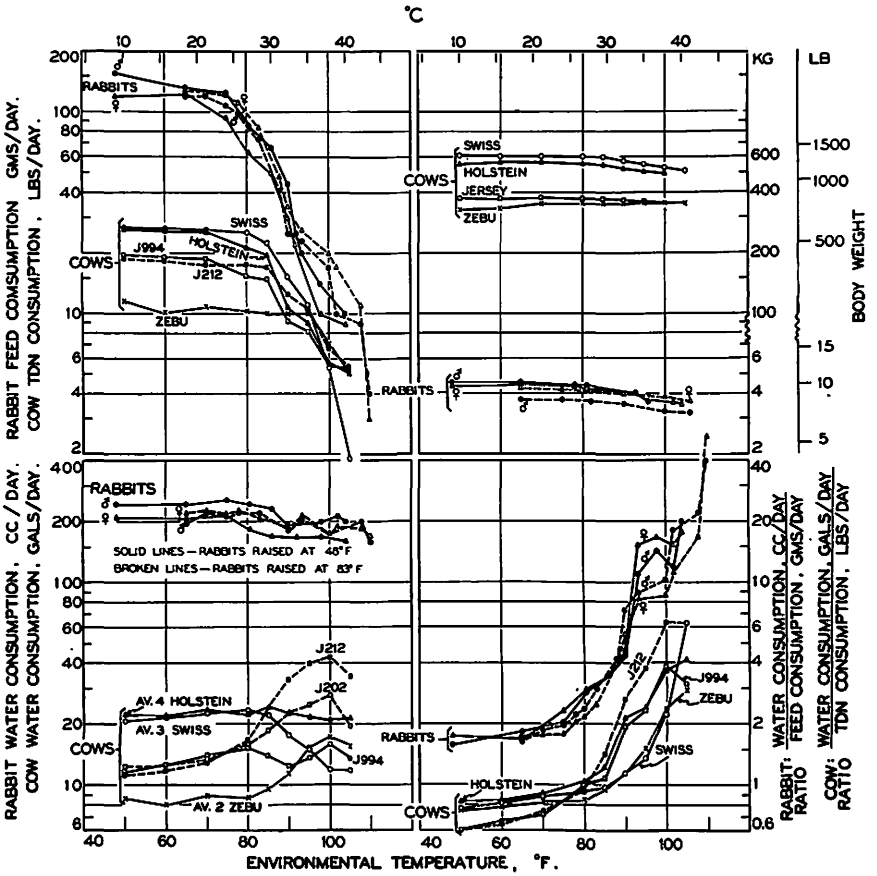

Figure 6. Feed or TDN consumption, water consumption, body weight, and ratio of water consumption to feed consumption of rabbits and cows at various environmental temperatures. (Cow data on TDN consumption, same as Figure 5; on water consumption, Mo. Agr. Exp. Sta. Res. Buls. 436, 460, and 471; and on body weight, Mo. Agr. Exp. Sta. Res. Buls. 449, and 471).

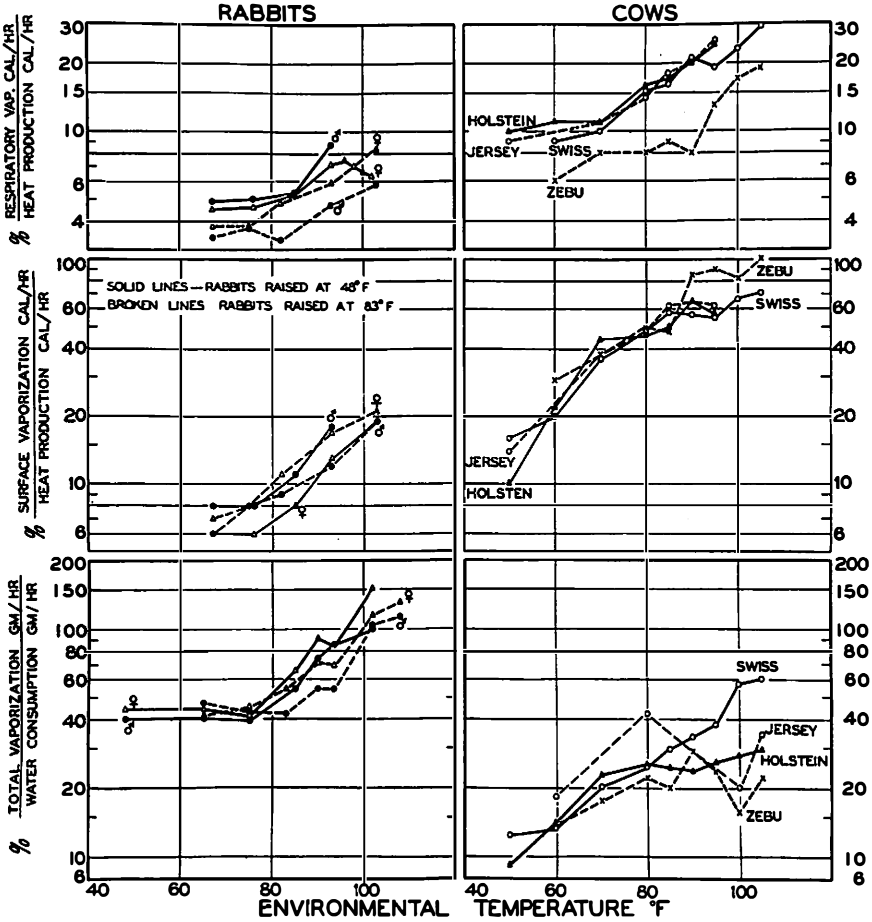

Figure 7. Ratios of respiratory vaporization to heat production, surface vaporization to heat production, and total vaporization to water consumption of rabbits and cows at various environmental temperatures. (Cow data on respiratory, surface, and total vaporization, same as Figure 3; on heat production, same as Figure 4; and on water consumption, same as Figure 6).

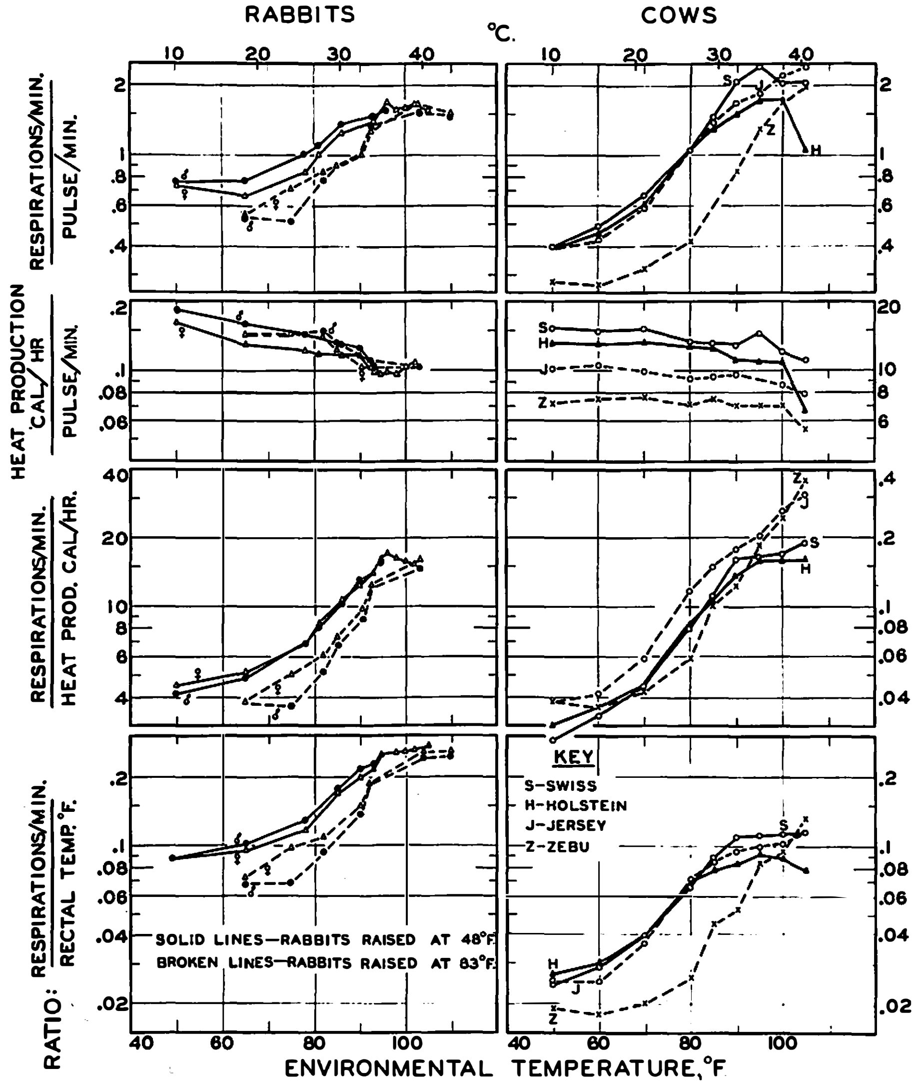

Figure 8. Ratios of respiration to rectal temperature, respiration to heat production, heat production to pulse, and respiration to pulse of rabbits and cows at various environmental temperatures. (Cow data on respiration rate, pulse rate, and heat production, same as Figure 4; on rectal temperature, same as Figure 1.)

TABLE 1--EFFECT OF RISING ENVIRONMENTAL TEMPERATURE ON VARIOUS PHYSIOLOGICAL REACTIONS OF NEW ZEALAND WHITE RABBITS REARED AT 48°F

Environmental temp. °F	Feed consumption gm/day		Water consumption cc/day		Rectal temp. °F		Heat production cal/hr		Insensible weight loss cal/hr		Thyroid I^{131} release rate k x 10^{-3}		Pulse rate per minute		Respiration per minute	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
50	152	120.5	244.9	209.8	103	102.9	22	19.9	2.4	2.2	12.8	11.2	118	122	90.5	90
65	133	124	243.8	209	103.3	103.2	21.5	19.1	2.4	2.2	14.4	9.6	133	147	104	98
78	105	77	251	190	103.3	103.4	19	17.4	2.4	2.1	13.2	9.6	131	141	132	120
81	91	60	243	192	104.4	103.8	18.2	16.5	-	-	8.5	7.6	132	138	146	139
86	67	50	232	170	104.8	103.9	17.9	16.6	3.0	2.6	3.8	5.2	136	141	186	176
90	44	30	193	138	105.9	104.3	17.6	16.8	3.4	3.0	1.8	3.6	139	143	229	207
93	28	11	225	157	106.3	104.7	17.0	16.1	4.6	3.5	1.3	2.9	162	163	242	229
94.5	12	11.5	215	181	106.6	104.9	16.1	15.1	4.5	3.3	-	-	164	156	255	243
96	-	-	-	-	-	-	-	15.4	-	-	-	-	172	156	270	265
98	14	10.5	200	169	106.7	105.3	-	16.4	-	-	-	-	172	169	-	267
100	-	-	-	-	106.8	105.8	-	17.3	-	-	-	-	220	168	-	273
102	18	9	213	139	106.8	106.1	-	18.3	-	5.1	1.02	2.34	-	168	-	280
105	10	9.4	200	160	107.0	106.2	-	-	-	-	-	-	-	182	-	290

TABLE 2--EFFECT OF RISING ENVIRONMENTAL TEMPERATURE ON VARIOUS PHYSIOLOGICAL REACTIONS OF NEW ZEALAND WHITE RABBITS REARED AT 83°F

Environmental temp. °F	Feed consumption gm/day		Water consumption cc/day		Rectal temp. °F		Heat production cal/hr		Insensible weight loss cal/hr		Thyroid I^{131} release rate $k \times 10^{-3}$		Pulse rate per minute		Respiration per minute	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
65	120	129	197	220	102.9	103.1	18.4	19.6	2.2	2.2	10.4	9.2	129	136	69	75
75	108	123	212	219	103.0	103.1	19.2	20.2	2.2	2.4	8.6	8.3	134	140	70	101
82	75	86	210	212	103.5	103.5	18.6	18.4	2.3	2.9	7.0	6.1	124	131	96	112
85	72	81	232	207	103.6	103.6	17.8	17.4	-	-	-	-	134	140	120	128
90.5	25	34	182	186	103.9	104.0	16.2	15.9	2.4	3.2	3.8	4.5	140	152	142	155
92.5	19	22	211	219	104.0	104.2	15.8	15.7	2.7	3.6	-	-	141	152	190	195
103	9.5	17	182	189	107.2	107.1	17.7	17.2	-	-	1.6	1.4	170	165	260	277
110	3.5	3	160	170	-	109.5	-	-	-	-	-	-	184	183	270	282