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The Effect of High Temperature and Humidity upon Cattle.

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Introduction.

The purpose of introducing European breeds of dairy and beef cattle into tropical regions is at least threefold: firstly, to promote agricultural development; secondly, to provide the European settler with a nutritive diet and, thirdly, to improve the diet of the natives, which is usually deficient in protein foods. Of particular importance are the dairy breeds; for in the production of milk the output energy is thirty-three percent of the input energy, as compared with five to fifteen per cent in the production of meat. Moreover, in spite of the greater labor cost involved in the production of milk, the price of whole fluid milk, in the United States in 1943, has been estimated at fifty cents per pound of dry matter and of dry skim milk only fourteen cents per pound, while that of meat at $1.10 per pound of dry matter. Finally cattle, being ruminants, can consume roughage and with the aid of rumen micro-organisms, they can synthesize "complete nutritional proteins from feed proteins and virtually all the B vitamins" (1).

Hence the significance of cattle husbandry to the general economy and to the health of the inhabitants of tropical regions is obvious. The European colonists, therefore, have almost invariably transported with them their cattle breeds wherever they established permanent settlements; for in some regions, such as the Western Hemisphere and Australia, indigenous breeds of cattle, whether of Bos taurus or Bos indicus, were absent. In other regions the native breeds were of inferior quality, of low productivity and of unfamiliar habits and characteristics. And as more advanced techniques and machines of Western Europe came to be employed for exploiting the tropics, the highly "efficient" European cattle breeds were imported increasingly into the tropics and subtropics in order to improve the local breeds or to replace them altogether.

However, the European dairy and beef breeds of the highest economic importance are highly specialized animals, which have evolved in a temperate climate. They have been produced by artificial selection during the past 200 years for very specific needs, economically and socially determined. The complex of inherited traits, which makes for efficient beef and milk production, is the product of selection for maximum productive efficiency within particular regions, enjoying definite climatic regimes, characterized by extensive seasonal climatic variations and by considerable daily weather fluctuations. The most important breeds, such as the Holstein, Jersey, Guernsey, Hereford, Shorthorn, Aberdeen-Angus, etc. have originated, thus, in those parts of northwestern Europe where the mean January isotherm does not fall below 35° F., the mean July isotherm does not rise above 63° F. (3) and where the specific atmospheric humidity is moderate but relative humidity is high. The area within these winter and summer isotherms constitutes a climatic zone in which body heat can be eliminated readily, since the air temperature is practically always considerably lower than the body temperature.

Genetic improvement, however, is never absolute; it always is relative to the pervailing environment. For every trait, whether morphological or physiological, is the end product of a chain of interactions of genes with each other, with the environment and with intermediate substances at every stage of development. The genes by themselves cannot develop a particular characteristic unless they are within the proper environment; nor will the environment cause a trait to develop unless the necessary genes are present. And a change in either the genes or the environment will alter a given trait.

This interdependence between heredity and environment determines the constancy and efficiency of breeds and their relativity. The indissoluble interrelationship of breed and environment has been aptly stated by F. A. Crew in the following words, viz.: "Ayrshires will continue to remain Ayrshires as long as they live in Ayrshire, which is not a county of Scotland but a peculiar combination of human stock, social organization, husbandry and climate. Transplant the Ayrshire and it will become different, either better or worse" (4).

These genetically improved animals respond to the moderate atmospheric temperature and humidity of their environments by means of inherited functional changes, which must remain within certain limits in order to maintain the animal in equilibrium with its environment, and hence to ensure its survival and promote its productivity. Moreover, the artificial selection superimposed upon natural selection has eliminated increasingly those individuals which were biologically and economically unsuitable for temperate climates. Intensive selection, aiming at attaining homogeneity of breed and reducing the latitude of genotypic and phenotypic variability, has produced very refined and delicately balanced animals, whose optimum phenotypic expression, in other words development, reproduction and productivity, requires the temperature and humidity prevailing in northwestern Europe or in other climatically similar areas. The genetic potentialities of the purebred stock conform as closely as possible to the climatic facilities presented by the environment for eliciting the best phenotypic expression. Those limits set by the environment must never be exceeded. For whenever the genotypic capacities of an organism are superior to its environment in general and to the climatic constituents of the environment in particular, it must adapt itself to a lower ecological plane (4). Its genetic endowment is deprived of maximum development and of the most efficient utilization of the environment, so that constitutional and functional deterioration ensue.

Therefore the high grade European breeds, which are the result of selection for maximum performance under specific climatic conditions, do not manifest the same qualities under climatic regimes to which their racial germ plasm has not been exposed perhaps for thousands of years, and for which they have not been selected by breeding. While the European breeds differ among themselves in their abilities to withstand high temperature, their optimum performance occurs in moderate temperate climates. With few exceptions, such as the Jersey breed, which fares well in the subtropics, they fail to thrive in the tropics and subtropics. Both the adults and their offspring, born in the new environment, become progressively less efficient than their counterparts in the temperate climates. Even when the nutritional plane is maintained at an optimum level, and diseases are under control, constitutional failure manifests itself. The first purebred generation born in the tropics and, more markedly, subsequent generations suffer a decrease in body size and weight; they acquire a leggy appearance; their skeletons become lighter and grow faster than their tissues. With their long matted hair they present an unthrifty appearance. Their milk output and beef production declines, their fertility is diminished and mortality is increased (5).

These adverse effects exerted by tropical climates upon European cattle breeds have long been evident and frequently commented upon. Nevertheless, careful studies of the direct influence of climate in general and of its individual constituents upon the physiology and morphology of imported breeds have rarely been attempted. Hence, while considerable information is available regarding climatic influences upon cattle much of it is contradictory, superficial and still in the stage of folklore.

Recently G. CURASSON (6) has summarized fully the recent data regarding the effect of tropical climate upon the physiological processes of the domesticated animals. However, while stressing the complexity of the interrelationship of meteorologic, nutritional and biotic influences he has not considered sufficiently the action of the individual climatic factors, in particular vapor pressure and temperature under carefully controlled conditions.

It is the aim, therefore, of this paper to summarize some of the significant facts of the direct influence of high temperature and high humidity upon cattle, not only upon European breeds but also upon Zebu and Afrikander and upon hybrides of those species. An attempt will be made to determine the extent to wich tropical climates, expressed in terms of high atmospheric temperature and high absolute humidity (also high temperature and low humidity), affect adversely European breeds of cattle and to assess the scientific value of the available data. In this connection will be considered the adequacy of existing information for drawing valid conclusions regarding the acclimatization of European breeds to tropical and subtropical climates, and the possibilities of counteracting the untoward effects of high temperature and humidity so as to enable the high grade stock to exist, reproduce and be economically productive in the tropics.

Climate is a complex entity comprised of the meteorological elements of air temperature, air humidity, atmospheric pressure, solar radiation and air movement (7). In order to understand the action of climate upon cattle the investigators have attempted to isolate the individual constituents, and have studied them separately. In such a procedure not only must the non-climatic milieu, such as nutrition, management technique and hygienic conditions, be maintained constant, but also all the components of climate except the one under investigation must be controlled. No valid conclusions regarding the significance of climatic factors in the life of an animal can be made unless care has been taken to control all but the one variable.

The Effect of High Temperature upon Body Temperature and Respiration Rate.

Atmospheric temperature is the most important climatic element affecting the life processes of cattle. It is also the easiest to measure and control under laboratory conditions. Similarly body temperature, respiration rates and pulse rates are important indices of the physiological state of the animal, and are also relatively easy to measure. Nevertheless, while numerous observations have been made upon the influence of high atmospheric temperature upon various breeds of cattle, studies of the action of temperature alone under laboratory conditions are relatively few and unsatisfactory, since they usually have failed to make temperature the only variable and to hold constant the absolute humidity of the air. In many of the experiments the relative humidity is kept constant, but a constant relative humidity with a variable temperature actually includes another variable, namely atmospheric vapor pressure, which increases as the temperature rises. And a high vapor pressure at high atmospheric temperature may seriously interfere with heat loss by means of vaporization of water from the lungs and skin.

This failure to take into account the simultaneous variations of atmospheric vapor pressure with rising temperature is evident in the work of REGAN and RICHARDSON (8). They subjected producing dairy cows of Holstein, Jersey and Guernsey breeds to artificial climatic conditions in a psychrometric chamber for about 24 hours. The air temperature was varied, but relative humidity and air velocity were held constant at 60 percent and 50 feet per minute respectively. The rectal temperature, the respiration and pulse rates were measured.

The following table illustrates the effect of high atmospheric temperature upon the experimental animals.

Temp. ° F.	Rel. Hum.	Vapor Pressure mm Hg	Average Rectal Temp.- ° F.	Average Respiration Rate per min.	Average Pulse rate per min.
80	60%	16.00	101.8	56	61
85	60%	18.50	102.2	70	59
90	60%	21.32	102.7	88	60
95	60%	23.47	103.7	106	57
100	60%	29.47 [1]	105.1	124	—

Up to an atmospheric temperature of 80° F. the respiration rate rose gradually from the normal average of about 30 to 56 respirations per minute and the temperature was within the normal range of 101-101.5° F. (8). Between 80 and 85° F., however, the upper limit of heat regulation of the producing cows is exceeded; heat production is greater than heat loss and the body temperature begins to rise. The increased rate of respiration represents the body's attempt to increase the elimination of heat by evaporation of moisture through the lungs, since cattle either do not sweat or

[1] Vapor pressure values have been calculated by the writer from the relative humidity and temperature data of Regan and Richardson.

sweat very poorly. Moreover, the pulse rate declines or remains almost unchanged presumably because in non-sweating animals there occurs no increase in the flow of blood to the skin surface in order to be cooled off. Instead the blood may be sent to the interior and its overabundance together with the associated oxygen reservoir may depress the pulse rate (9).

Further investigations of the action of temperature and atmospheric humidity upon cattle have not utilized the psychrometric chamber, in which the several climatic components can be separated and rigidly controlled so that their individual and combined effects can be properly analyzed. Instead numerous studies, under controlled field conditions, have been made of the responses of both dairy and beef types of European and of Zebu and Afrikander cattle to climatic conditions in which high temperature was associated with high and relatively low atmospheric humidity. Also the progeny of crosses between European cattle with Zebu or Afrikander were similarly studied. The body temperatures, respiratory and pulse rates were recorded at the various temperatures. As before the role of vapor pressure as an independent variable continued to be neglected; relative humidity was measured seemingly without any clear realization of the physiological implications of the absolute atmospheric vapor pressure and temperature as independent influential factors.

Differential Response of Different Breeds of Cattle to Temperature.

Under field conditions European dairy and beef cattle manifest a rise in body temperature and in respiration rate, which runs parallel to the daily elevation in temperature and which is most marked when the atmospheric temperature is very high. While the normal, average diurnal range in the rectal temperature of a producing cow is approximately between 101° and 102° F. high atmospheric temperature causes a higher elevation and wider range in body temperature. However, the reaction of the different breeds of European origin is not the same in spite of the fact that they all originated within approximately the same climatic area. Jersey cows, for example, can tolerate high temperature and high humidity better than other European breeds.

This intraspecies difference in the tolerance of heat is illustrated in the following table, in which the body temperatures and respiration rates of producing Jersey and Holstein vows under identical conditions are compared. These observations were made in the Imperial Valley of California, where the mean monthly temperature is above 75° F. for six months of the year, above 85° F. for four months and reaches 90° F. for two months. They clearly indicate that the Jersey cows are better capable of withstanding the hot dry climate (10).

	Max. Air. Temp. °F.	Min. Air. Temp. °F.	Body Temperature Holstein AM	Body Temperature Holstein PM	Body Temperature Jersey AM	Body Temperature Jersey PM	Respiration Rate per Min. Holstein AM	Respiration Rate per Min. Holstein PM	Respiration Rate per Min. Jersey AM	Respiration Rate per Min. Jersey PM
May	85	57	101.3	101.9	101.3	101.6	30	50	27	36
June	104	74	101.5	101.4	101.6	102.0	51	59	39	51
	108	68								
July	108	68	102.6	104.0	101.5	103.0	78	96	44	82
	112	81	101.7	103.0	101.0	102.6	65	88	46	80
Aug.	108	82	102.8	102.9	101.3	103.2	77	82	54	72
	107	79								
Oct.	81	50	101.0	102.0	101.4	101.3	31	38	23	30

Thus in the hot dry climate of the Imperial Valley the Jersey breed experiences a smaller increase in body temperature and in respiration rate both with the daily and seasonal rise in atmospheric temperature.

Under the hot humid climate of the Philippines, as well as in the southern subtropical states of the United States, the Jersey dairy breed shows a superior heat tolerance. It is reported that the average morning body temperature of producing Jersey cows is 101.23° F. and the afternoon temperature 101.88° F., while for Holstein Frisians under identical conditions the corresponding body temperatures are 101.64° and 102.56° F. respectively. Moreover, the daily range of the body temperature of Jerseys and Holsteins in the Philippines was from 98.78° to 105.8° F. for the Jerseys and from 99.5° to 106.52° F. for the Holsteins. In the temperature zone of the United States the daily range for the former is 96.3° to 102.3° and 100.4° to 102.74° F. for the latter (11).

Furthermore, evidence has been presented which indicates that the Holstein and Jersey breeds differ in their reactions to an increase in atmospheric vapor pressure when the air temperature is maintained constant (12). While the correlations between body temperature and humidity are very small, an increase in humidity at constant temperature was associated with somewhat higher body temperature and respiration rate in Jerseys and with lower body temperatures and lower respiration rate in Holsteins. Thus, an increase of 1° F. in the air temperature caused a rise of 0.1007° F. in the body temperature of Jerseys and of 0.1919° F. in that of Holsteins. On the other hand, a 1 per cent increase in relative humidity, which actually amounts to a 2% increase in vapor pressure, increased the body temperature of the Jerseys by 0.00758° F. and lowered the body temperature of the Holsteins by 0.0321° F.

No definite conclusions can be drawn from these data. They are based upon a statistical analysis of a small number of observations made under field conditions, and they have not been confirmed by the same experimenter in a second trial. They merely serve to indicate the possibilities present in a more refined analysis of the independent effect of temperature and humidity upon cattle.

Effect of High Temperature and Humidity upon the Body Temperature and Respiration Rate of Zebu and Afrikander Cattle.

In contrast to animals of Bos taurus, to which the European breeds of cattle belong, the breeds of Bos indicus, the Zebu and Afrikander for example, are not influenced as markedly by high air temperature and humidity. No data are available on the behavior of Zebu or Afrikander cattle in psychrometric rooms where temperature can be made the only variable. All data refer to the behavior of these animals under controlled field conditions.

The reactions of purebred Zebu to high atmospheric temperature and humidity are similar to those of European breeds except that they are not as extreme and marked. Indian cattle, the Mariana breed for example, show a diurnal rise in body temperature, which is associated with the daily rise in air temperature from morning to evening. Their mean daily body temperature is highest during those months of the year when the air temperature is highest. During June and July, when the air temperature ranges between 81° and 106° F. and 84° and 108° F. respectively, the body temperature averaged 101.41° and 101.35° F. In August and December, on the other hand, when the range of air temperature was 73-102° F. and 48-78° F. respectively, the corresponding body temperatures were 101.09 and 100.99° F. It is true that the difference is slight; nevertheless it reveals a significant trend (13).

The following table clearly illustrates the differential response of breeds of Bos taurus, of Bos indicus and of the progeny of interspecies crosses to high temperature (14) [2].

			Body Temperature			Respiration		
Hrs. of day	Air Temp. °F. in sun	Shade Temp. °F.	Hereford	Shorthorn	F_1Afrikander Shorthorn	Hereford	Shorthorn	F_1Afrikander Shorthorn
8	80.96	78.08	102.2	102.74	102.02	48	78	40
9	82.07	78.92	102.38	103.10	102.02	49	92	39
10	84.02	82.94	102.56	104.18	102.02	58	102	45
11	84.02	82.94	102.56	105.62	102.02	71	112	39
12 M	89.96	89.96	102.74	107.24	102.02	85	141	42
1 PM	93.92	90.50	103.20	105.98	102.02	94	121	41
2	98.98	91.94	103.10	105.80	102.20	95	112	48
3	100.94	93.92	103.28	105.62	102.20	98	112	48
4	100.40	93.02	103.10	106.16	102.38	92	116	42
5	95.00	93.02	102.56	106.38	102.02	82	116	44

[2] These observations were made at the Messina Experimental Station, South Africa.

Another example of the differential effect of high air temperature with rather low atmospheric humidity upon European and Zebu, and crosses of these breeds is illustrated by the following observations from Naivasha, Kenya (15).

Shade Temp. °F.	Vap. Press. of atmosphere- mm Hg.	Body Temperature			Respiration Rate per Min.		
		Zebu	Ayrshire	Cross	Zebu	Ayrshire	Cross
51—55	6.4	100.8	100.9	101.1	21	30	27
56—60	9.5	101.2	101.6	101.2	23	35	25
61—65	9.4	101.4	102.3	101.7	25	38	34
66—70	11.6	101.6	102.5	101.9	29	45	37
71—75	10.1	101.7	102.9	102.0	34	51	39
76—80	10.0	101.7	103.1	102.2	35	56	44

Accordingly like European breeds, Bos indicus or Zebu cattle manifest a rise in body temperature and respiration rate as the external atmospheric temperature increases. However, the elevations in body temperature remain within the normal range of variations at the same time that the body temperature of the European breed, the Ayrshire, has risen considerably above it. Offspring of the crosses of these breeds have remained intermediate in their reactions to identical climatic stimuli.

Further confirmation of the greater tolerance of Zebu and hybrids of Zebu and European cattle is presented by the following observations made in Minas Gerais, Brazil (16). Pure Holstein-Frisian, pure Zebu (Gujerat type) and Holstein-Frisian and Zebu hybrids were subjected to air temperatures, which ranged from 51.8° to 96.8° F. and which are harmful to milk production and growth of European cattle. The effect of these temperatures upon respiration rate is illustrated by the following data.

Average Respiration Frequency Per Minute

	51.8° F.	66.2° F.	73.4° F.	84.2° F.	96.8° F.
Pure Frisian	28.0	30.2	44.4	92.4	107.0
Frisian-Zebu cross	20.0	22.4	29.8	74.0	89.3
Zebu	23.0	23.0	27.0	34.5	46.0

Between 51.8° and 66.2° F. the respiratory rate of these diverse genotypes is similar. However, et 73.4° and 96.8° F., when the atmospheric temperature begins to approach more closely the body temperature, a marked difference becomes apparent among the respiratory rates of the several genotypes. Within this range the respiration rate of the Holstein increased by 52.6 respirations per minute, that of the hybrid by 58.5 and that of the Zebu by only 19. The Holstein and the hybrid experience the greatest increase between 73.4° and 84.2² F., while the Zebu show the highest rise

above 84.2° F. Above 84.2° F. respiration rate of the Holstein and the hybrid rose only by 11.5 respirations per minute. Although these observations are not very numerous, it seems that both the Holstein and hybrid attain their maximum adaptability at a temperature range within which the respiration rate of the Zebu has risen relatively slightly. The latter probably reaches its maximum adaptability at a temperature above 96.8° F.

The degree to which the offspring of crosses between Zebu or Afrikander breeds with European breeds tolerate high atmospheric temperature depends upon the amount of Bos indicus blood in the hybrids. This may be seen in the following table:

Air Temp. °F.	Aberdeen-Angus pure breed	¾ Aberdeen-Angus ¼ Brahman	½ Aberdeen-Angus ½ Brahman	Brahman pure
		Rectal Temperature °F.		
46—55	99.7	101.0	100.5	99.2
76—85	101.7	101.4	101.0	101.0
86—95	102.8	101.9	100.9	101.0
		Respiration rate/minute		
46—55		44.4	31.8	28.5
76—85	88.3	74.2	44.8	32.7
86—95	102.2	105.4	55.1	36.8

Furthermore European, Zebu and cross breeds seem to manifest breed differences in the amount of water transpired through the skin. At a temperature range of 86-95° F. the pure Aberdeen-Angus lost 96.5 grams of water per hour, the ¾ Aberdeen-Angus 111.6 grams per hour, the ½ Aberdeen-Angus 183.4 grams per hour and the Brahman 176.2 grams per hour. While the observations upon which these averages are based are few, it seems that the higher tolerance of the Zebu is associated with its greater capacity to transpire water through the skin. The seeming superiority of the ½ Aberdeen-Angus may be either a matter of chance or a result of the fact that the atmospheric temperature is not yet sufficiently high to permit the expression of the maximum transpiration capacity of the Zebu (16).

Relative Importance of the Effect of Atmospheric Temperature and Atmospheric Humidity upon Body Temperature and Respiration Rate.

An experimental separation of the effect of high air temperature and high vapor pressure upon cattle would be valuable in analysing the problem of acclimatization of cattle to tropical climate. Although the need and value of such a procedure is obvious, it nevertheless has never been adequately undertaken. It is reported that, as compared with air temperature, relative humidity is less important in affecting adversely body temperature, respiration rate and pulse rate. A one degree increase in air temperature is presumably responsible for 13 to 15 times as much increase in body temperature as a one percent increase in relative humidity. Similarly one degree rise in air temperature causes 41 to 43 times as much change in respiration rate as a one percent change in relative humidity. An increase in relative humidity actually slowed down the respiration rate. Moreover, while the correlation between air temperature and body temperature is highly significant and positive, that between relative humidity and body temperature is slight and negative. Hence an increase in relative humidity at high temperature, that is a rise in vapor pressure, by reducing the rate of respiration rate, would interfere with the dissipation of heat and hence contribute to the overheating of the organism (12). The significance of this evidence is difficult to assess, since the statistical analysis is based upon very small numbers and, in so far as the effect of temperature and humidity upon respiration rate is concerned, contradictory results were obtained in two different tests during two different years. Finally, those studies are based upon observation at only one temperature.

Effect of High Atmospheric Temperature Upon Milk Production.

The rise in body temperature and respiration rate as a result of high environmental temperature, which is indicative of profound physiological changes within the animal, is accompanied in the case of the dairy cow by a decline in milk yield. Indeed producing dairy cows manifest greater discomfort than dry cows during hot months, and high producing cows have higher body temperatures and respiration rates than low producers. Very high yielding cows must be more efficient eliminators of heat in order to dispose of the excess heat incident to the heavy consumption of food and production of milk. Conceivably differences in heat tolerance may be associated with differences in food consumption so that higher tolerance depends upon lower food intake.

The harmful effect of high environmental temperature upon milk production is illustrated by the previously cited experiment (8) in which the behavior of producing Jersey, Guernsey and Holstein dairy cows under high temperature was studied in a psychrometric chamber. Both the quantitative and qualitative changes which accompany the rise in air and body temperature are summarized in the following table.

Air Temp. °F.	Body Temp. °F.	Milk yield per cow day lbs.	% fat	% non-fatty solids	% casein
40	101.8	29	4.2	8.26	2.26
80	102.2	25	4.0	7.84	2.07
85	102.7	23	3.9	7.68	1.93
90	103.7	20	4.0	7.64	1.91
95	105.1	17	4.3	7.58	1.81

Up to an air temperature of 80° F. the milk yield remained fairly constant. However, as soon as hyperthermie was reached a marked change took place in the daily milk output. The decline in milk yield was very rapid and at 95° F. it amounted to over 41 percent. The percentage of butter fat, on the other hand, remained practically unaffected. However, above this temperature its composition undergoes a change; its constituent fats become more unsaturated and it contains fewer of the lower fatty acids.

Milk production is lower and of inferior quality during the summer months especially when they are hot and dry, even when the adequate nutritious food is available. This seasonal decline in milk yield is clearly evident from the following observations on Holstein and Jersey cows in the Imperial Valley of California. During July the average 24 hour temperature was 79° F., and there were only ten nights during which the air temperature was below 75° F. The marked drops on several days during August, September, and October coincided with several hot nights during which the temperature was above 75° F. (10).

Effect of Seasonal Rise in Temperature upon Daily Milk Yield of

Date	Holstein Cows			Jersey		
	Body Temp. °F. AM	Body Temp. °F. PM	Milk Yield in lbs. day per cow	Body Temp. °F. AM	Body Temp. °F. PM	Av. Milk Yield in lbs./day per cow
May 10	101.0	101.7	52.9	101.3	101.6	29.5
June 4	101.6	103.3	48.3	101.6	102.1	27.9
12						
July 8	102.6	104.1	37.2	101.5	103.0	23.6
9						
Aug. 8	102.5	104.2	30.3	101.0	102.6	24.4
9						
Sept. 6	102.4	103.4	27.9	101.3	102.2	23.2
Oct. 7	101.0	101.6	22.2	101.4	101.3	19.0
8						

Both the Holsteins and Jerseys thus showed a decline in the daily milk yield which is associated with the high environmental temperature. However, the decrease was unequal since under the same climatic conditions the Holstein output was reduced by 58% while that of the Jersey by only 36 per cent.

The reduction in milk output by European purebreeds in the humid tropics, even when nutrition is balanced and infectious diseases have been eliminated, is a matter of common knowledge. A reduction of 56 percent in yield per lactation has been reported for Holstein dairy cows in Vicosa, Minas Gerais, Brazil (17). Under the same conditions offspring of crosses between Brahman and European breeds have had a milk production which was better than that of the Brahman and inferior to that of the European parent.

An indication of the inter-relationship between high temperature and milk yield is afforded by the following example. In a Singapore dairy farm Holstein cows were kept during the summer months in an air-conditioned barn, in which the air temperature was maintained at 70° F. and the relative humidity at 60%. The daily milk yield of these cows was 24 pounds while previously, when they were maintained in ventilated barns, the daily yield amounted to only nine pounds (18).

Studies on the effect of temperature upon milk production of Zebu cattle are very few. For one thing the number of high milk producers among this breed is very small. Moreover, in these areas where Zebu cattle are maintained in large numbers no psychrometric rooms are available for studying the influences of air temperature and air humidity upon milk yield. Indeed the individual effect of high temperature and high humidity upon European cattle under adequately controlled climatic conditions has never been investigated satisfactorily.

The reduction in milk yield under the influence of high temperature can scarcely be explained on the basis of existing knowledge. It is "possible that at higher temperatures the usual milk precursors are not supplied to the mammary glands either at the same level as in the blood or at the same rate—a hypothesis that is lent some support by the fact that the pulse rate is slowed down at high air temperatures". Above 80° F., moreover, the water consumption and food intake decline so that the effect of temperature on milk output is also indirect (19).

The production of milk is a very complex process closely associated with the endocrine system, especially the pituitary and thyroid. The anterior pituitary in turn is influenced by light; increasing quantities of light stimulate its function. Yet to what extent light, through its effect upon the anterior pituitary, acts with temperature to influence milk production is not known. Hitherto investigators have measured the daily milk yield and the associated daily and nocturnal temperatures, but correlations of milk yield with endocrine changes, analysis of the rate of air temperature, light and air humidity are lacking.

The Effect of High Atmospheric Temperature Upon the Grazing of Cattle.

For range cattle and for those obtaining their food chiefly by grazing, the effect of climatic conditions upon grazing habits is of great significance. The grazing habits of a group of Jersey and Holstein milking cows were studied during two relatively warm days (mean air temperature 86 and 85° F.) and one cool day (mean air temperature 72° F.). On the warm days the animals manifested the elevated body temperature and respiration rate characteristic of the physiological reaction to high air temperature. During the 24 hour period of each warm day the animals grazed 1.9 and 1.8 hours between the morning and evening milkings, while at night between the evening and morning milkings they grazed 6.5 and 6.2 hours. On the other hand, on the cooler days the daytime grazing amounted to 4.5 hours and the night grazing to 4.7 and 5 hours. Moreover, the total grazing time was one hour longer on cool than on warm days (19).

The effect of temperature upon the grazing habits of European, Zebu and hybrid breeds is analogous to its effect upon body temperature. An examination of a mixed herd of Aberdeen-Angus, Brahman and grades grazing on a hot sunny day revealed that the Aberdeen-Angus spend considerably less time in grazing than the other types. The Aberdeen-Angus spent more time in the shade than the ¾ Aberdeen-Angus, who in turn spent more time in the shade and less in grazing than the purebred Brahman. The latter rarely sought the shade; they remained in the open pasture even when not grazing. Furthermore, while the purebred and ¾ Aberdeen spent less time in grazing under bright summer conditions, they grazed more frequently than the half-bred Aberdeen and purebred Brahman (15).

The Effect of Temperature Upon Reproduction.

There is considerable evidence that high atmospheric temperature influences the reproductive efficiency of cattle. For example, in a study of the breeding efficiency of tested sires of various European cattle breeds it was found that sires used at experiment stations in the southern states of the United States had an average fertility efficiency of 36 percent while those used in the northern and western stations had an efficiency of 49 percent. This difference has been attributed to the high summer temperatures combined with the high humidities prevailing in the southern stations. Also in northern and western stations the summer temperature may rise quite high, yet the nocturnal drop in temperature exerts a mitigating influence (20). The general belief prevails that in the northern hemisphere the period between July and September is characterized by the lowest fertility and that fertility increases in the fall. This phenomenon is attributed to the adverse effect of hot weather upon the genital organs (21).

The reproductive function upon which fertility depends is admittedly complex and it undoubtedly interacts with the various climatic constituents, in particular temperature and humidity in a multiplicity of ways. Therefore some understanding of the interaction between climate and fertility can be attained by a study of the influence of high temperature upon individual aspects determining fertility. Of such a nature are the recent investigations of the quality of semen obtained from proven sires, during the summer months, for artificial insemination.

Thus seasonal fluctuations in the production of spermatozoa in cattle of European breeds have been reported (21). Jersey, Guernsey and Ayrshire bulls produce semen of the poorest quality during July, August and September and of superior quality during April, May and June. The herd tested was located in Purdue, Indiana; and management and plane of nutrition were similar throughout the year.

The spermatozoa produced during the summer had the lowest initial and total motility, the lowest general survival period and the highest number of abnormal individuals. The average volume of semen per ejaculations was least and the average number of sperm per cubic millimeter of semen and the total number of sperm per ejaculation was significantly lower than in the spring (22.). Moreover, more services were required per conception during the summer months than during any other months of the year.

Many of the trends in semen production seem to follow the temperature curves rather closely. The average number of abnormal spermatozoa increased more than 25% during July, August and September. The total motility, the initial motility, survival, concentration, and volume of ejaculate were least when the atmospheric temperature was at a maximum.

The decisive influence of temperature upon semen quality cannot unequivocably be deduced from these observations. Temperature, humidity, and quantity of light vary from season to season. At best the influence of temperature may be partial, since quantity of light exerts an effect on the sexual activity of animals.

It is perhaps owing to the failure to determine more precisely the effect of temperature upon semen quality by strictly controlled experimental techniques that wide disagreement exists regarding the relationship of high temperature to semen quality and bull fertility. Thus purebred Hereford in Bylos, Arizona, which is 4300 feet above sea level and where the summer temperature rarely exceeds 95° F. failed to show inferior semen quality and diminished fertility during the summer months (23). While seasonal variations were observed in the quality of semen it was not inferior during the summer months, from May to September. In contrast to the preceding observations the semen volume, the rate of production, and the concentration of sperm per ejaculations was highest between May and September and the percentage of abnormal sperm remained unchanged. And fertility as measured by number of services per conception was highest during the hottest and driest period, from May to September (23).

Furthermore, a statistical analysis of the fertility records of herds of Ayrshire, Holstein and beef and dual purpose shorthorn cattle located in farms of Eastern Canada between latitudes 45° and 49° latitude seems to indicate that bull fertility, measured by successful services per conception is highest during the summer and lowest during the spring and winter. The poorest conception rate occurred in February and the best in July some time after the shortest and longest days of the year, respectively. Hence the authors of this study (23) attribute the higher fertility in the summer months to the greater length of the day.

Whatever may be the cause of this higher bull fertility in this instance the data certainly do not permit the conclusion that light is the responsible factor. Since in this case the mean monthly summer temperature never reached 70° F. during the period analyzed it is conceivable that summer temperature may exert a beneficial influence. Moreover nutrition may be more favorable during the summer than during the rest of the year. Finally the relationship between light and fertility in domesticated cattle, as well as in other mammals, is quite obscure.

Effect of Temperature upon the Fertility of Zebu Cattle.

The effect of high temperature upon the bull fertility of Zebu and Afrikander cattle is a matter concerning which very little precise information is available. There exists a general belief, not based upon evidence that can withstand scientific scrutiny, that the fertility of the Afrikander bull is unaffected by high temperature because the skin of his scrotum is twice as thick as that of bulls of European breeds and that at high temperature the scrotum is retracted causing the skin to be puckered and become a poor heat conductor. However, in both the case of the Afrikander and

Zebu seasonal fluctuations in the sexual activity and in fertility of the females have been noted (24).

The effect of temperature and atmospheric humidity upon the periodicity and duration of oestrus in Zebu and grade cattle was studied at Naivasha, Kenya. This is not a region of extremely high temperature, for the mean monthly maximum ranges between 60.2° and 63.3° F. and the highest temperature recorded during the observations was 83.3° F. The annual precipitation was over 32 inches. The climate may be considered warm temperate.

The duration of the oestrus cycle was taken as an index of fertility, because a long oestrus cycle is associated with shorter heat periods and hence reduced fertility and vice versa. In general higher temperatures were associated with shorter oestrus cycles and longer heat periods and lower temperatures were correlated with longer oestrus cycles and shorter heat periods. Accordingly higher atmospheric temperatures favored fertility. Furthermore, increased atmospheric humidity was associated with longer oestrus cycle and lower fertility.

To determine the factors responsible for the increased sexual activity as reflected by the length of the oestrus cycle is impossible from these data. Temperature is not isolated from sunlight; both vary simultaneously and in the same directions, and it is common knowledge that light is associated with reproductive activity.

It is quite apparent that the knowledge regarding the influence of climate upon fertility is fragmentary, conflicting and far from satisfactory. The fault lies not so much in the complexity of the problem but in the inadequate experimental procedure adopted for its solution. In none of the experiments has there been any attempt to dissociate the influence of light from that of temperature, and the role of humidity is neglected almost entirely. The intimate connection of endocrine activity with reproduction is a phenomenon militating against a simple direct effect of temperature upon reproduction. Nevertheless, no attempt has been made to investigate the endocrine balance of the animals during the periods when the effect of climate upon them was being studied. This lack of sound knowledge of the effect and mode of climate upon fertility is true not only of Zebu but also of European breeds.

While it is true that European breeds of cattle manifest diminished fertility in tropical climates (3, 4, 7) it is by means certain that the direct effect of temperature is the dominant factor involved. To ascribe the loss of fertility to elevate scrotal temperature is to simplify to absurdity a highly complex physiological problem and to bar the way to a possible explanation.

Some Characteristics of Cattle of Possible Aid to Heat Tolerance.

The question arises as to what are some of the physiological and morphological properties that might possibly endow the Jersey breed and Zebu cattle with superior tolerance of high temperature and humidity. All the answers are conjectural; at the present state of knowledge of the general physiology of cattle and of the special aspects of heat regulations adequate answers are impossible.

The ability of the Jersey to withstand high temperature is attributed to the fact that it is a small animal possessing a large skin surface per unit weight, and thus provides a larger surface for the evaporation of transpired moisture and for the loss of heat by radiation. A large surface, however, is advantageous only when the temperature of the surrounding air is lower than body temperature; it is equally favorable for the absorption of heat when the external temperature is above body temperature.

While morphological differences within breeds of Bos taurus possibly accounting for differences in heat tolerance are not known, such differences have been reported to exist between Bos indicus and Bos taurus. As compared with the Holstein-Frisian the Zebu has a much thinner skin; its hair development is about twice as great as that of the Holstein-Frisian so that the skin glands are better developed than those of the latter. Both functionally and structurally the sebaceous glands are identical; but those of the Zebu are larger and more numerous. The sweat glands of the Zebu are about twice as numerous and their coilings are twice as large as those of the Holstein. Nevertheless, it is not known whether the sweat glands of either breed are functional and participate in heat regulation (25).

The color of the coat is regarded as playing a role in heat regulation by influencing the amount of sunlight that is reflected from the skin. Dark colors presumably tend to increase the absorption of solar radiation and increase the heat load of the animal. Rather crude measurements of the reflection of light from various coat colors indicate that white Zebu coat absorbed 45% of solar radiation impinging upon it, the black hairy coat of Aberdeen-Augus 89%, the cream Simmenthal 50%, and the Red Afrikander 78%, and the Sussex red 93% (3, 26).

Whatever may be the significance of these figures their relationship to heat tolerance to body temperature and respiration rate is not clear. That coat color may be overshadowed by other factors and even may be irrelevant in heat tolerance is illustrated by the fact that in spite of the differences in heat tolerance manifested by such black coated cattle as the half-bred Brahman-Angus, half-bred Afrikander-Angus, ¼ Brahman-¾ Angus and purebred Aberdeeen-Angus, there was very little significant difference in the reflection of sunlight from their coats (27).

The thickness of the coat and the structure of the hair fiber unquestionably are of importance in the heat regulation of cattle. The critical temperature of unclipped cattle lies several degrees below that of clipped animals so that the body temperature of the latter begins to rise under a lower environmental temperature (28). Nevertheless, it is difficult to assess the role of different types of coats upon heat regulation since the insulation depends upon the length and internal structure of the fiber (3), upon the position it takes relative to the body and upon the air held within the interstices (27).

Conclusion.

While this survey of the literature dealing with the effect of high temperature and high humidity is by no means thorough it does indicate that knowledge of this problem is in a primitive stage. That high temperature and humidity raise the body temperature and respiration rates and diminish the productivity of European breeds to a greater extent than those of Bos indicus breeds is an established fact, although the specific roles of temperature and humidity have not yet been adequately studied. However, the specific significance of those adverse effects has never been expressed in microphysiological terms. There has been no satisfactory attempt to correlate these reactions with the endocrine and blood picture of the organisms. Instead the tendency has been to oversimplify explanations and reduce the very complicated mechanisms of internal heat regulations to differences in body color or weight of coat—the latter in itself being intimately connected with the endocrine functioning and nutritional balance of the animal.

Moreover, the data regarding the effect of temperature upon fertility and reproduction are in a state of confusion. Contrary evidence is presented; temperature exerts both a deleterious and favorable influence upon the fertility of cattle. This lack of agreement is primarily the result of improper experimentation, namely the failure to control and isolate not only the climatic elements of temperature, light and humidity, but also the non-climatic factors such as nutritions. In addition while it is known that fertility is closely associated with age there has been little attempt to study the interrelationship of climatic factors and fertility in bulls or cows of particular age groups. Thus, some of the studies on bull fertility indicate that high temperature may affect differently the semen of young and old bulls (30, 31, 32). But the cardinal fault of the studies on the interrelationship between climate and fertility has been the failure to take into account the factor of sunlight and endocrine functioning. Oversimplification of the problem does not lend to its understanding.

The present state of scientific knowledge regarding the influence of high temperature and humidity upon cattle confirms the general belief and experience that European dairy and beef breeds (with few exceptions) do not thrive in tropical and sub-tropical climates because of their inability to tolerate long periods of high temperature and high humidity. However, the precise reason for this incapacity is not known. The microphysiological conditions and reactions involved in tolerance and intolerance of high temperature and humidity are virtually a terra incognita. Hence possibilities of counteracting adverse climatic influences by artificial means are limited and of slight value. Frequent clipping of animals during hot seasons, cooling them down with showers (33) to increase evaporation from the surface and thereby reduce body temperature, and providing more abundant fodder during the short grazing periods are some rough measures for counteracting high temperature. Yet there is no doubt that more profound knowledge of the mechanism involved in the interaction between animal and climate, the prevailing endocrine balance for example, would provide new means for aiding cattle to tolerate better high temperature, increase their productivity and influence their fertility.

Finally, it is not only physiology of acclimatization of cattle that requires further study. The entire concept of climate must be revalued. For just as plants are said to have their own microclimates which are distinct from the general climates so animals must also have their specific microclimates. At present the climatic indices which are utilized in studies on cattle are the same ones devised specifically for human beings. It is therefore necessary to study the possible existence of a microclimate for cattle.

At present the only possible way of utilizing the economically valuable traits of the European purebreds is to cross them with Zebu, Afrikander or other native breeds of cattle. It is quite clear that the range of variability in body temperature, respiration rate and productivity are definitely inherited traits. Hence, the intercrossing of European with cattle native to tropical areas is widely practiced. However, the upgrading of native cattle cannot be unlimited. A too great infusion of European into native breeds eventually cancels out the advantages of species crosses.

In the Gulf Coast of states of southern United States, for example, the best results are obtained by grading up a foundation herd with purebred Hereford bulls, then crossing the first generation heifer offspring with the Brahman bulls and finally backcrossing the hybrid offspring with the Herefords. The resulting animals are $^5/_8$ Hereford, ¼ Brahman and $^1/_8$ foundation herd. In general hybrid cattle with one-fourth to one-half blood of a Brahman breed and remainder from a purebred European beef herd manifest the best adaptation to tropical and subtropical conditions. After the second, third and fourth top crosses the high grades lose their vitality and thriftiness. Their growth becomes stunted; their development is retarded especially after weaning. They become leggy; they acquire a heavy coat and scraggy appearance. They lose weight and their constitution and finally degenerate.

However, in so far as breeding cattle for tropics and subtropics is concerned, it is highly probable that the best results can be attained by selecting superior germ plasm from native breeds. The ancestors of the present high grade European cattle were probably not much better than the present native cattle of India and Africa. Careful selection for about two hundred years, of which perhaps only about thirty years involved scientific breeding, have produced the highly productive Jerseys, Holsteins, Herefords, Shorthorns, etc. It is very likely that the present phenotypically inferior breeds of Bos indicus contain genes which, if properly selected, would eventually give rise to purebred productive animals of high economic value. The inferiority of the Bos taurus breeds is paralleled by the so-called inferiority of the native peoples of India and Africa and the superiority of the European breeds has its counterpart in the superiority of Western European peoples and their offshoots. The present inferiority of the colored peoples is admittedly not genetic, but cultural. Perhaps the inferiority of their animals is also non-genetic but cultural and hence not a predestined inferiority but one capable of modification and transformation.

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Summary.

A survey of the literature dealing with the influence of high air temperature and high air humidity upon the physiologic reactions of cattle reveals a lack of satisfactory experimental data. The adverse action of these climatic elements upon the body temperature, respiration and pulse rates and productivity of European cattle is an established fact. On the other hand the data regarding the effect of temperature upon fertility are contradictory.

Very few attempts have been made to study under carefully controlled experimental conditions the effect of temperature under constant humidity or of humidity under constant temperature. Moreover, the mode of action of these meteorologic elements in relation to specific microphysiological processes, such as the action of endocrines for example, is relatively unknown. The studies of the effect of high temperature upon fertility have failed to consider the age of the animals and the influence of sunlight, which is intimately related with the function of the sex glands.

Finally it is not only the physiology of acclimatization that requires more extensive investigation. For just as plants have their own microclimates, animals also have their specific microclimates. Yet while these microclimates which are the climates within the first two meters above the ground surface, differ considerably from the "climate" proper or macroclimate, the climatic indices prevailing outside the microclimates have been utilized to describe the climate of animals whose acclimatization was studied.

It is likely that scientific breeding of native Zebu and Afrikander cattle may yield eventually strains of superior animals, which will be as productive as European cattle. Never the less,

more precise investigations of the influence of temperature, humidity and other strictly climatic elements upon cattle would provide valuable data that would facilitate the acclimatization of cattle, enlarge the environment within which European cattle could be productive, and also help improve the productivity of "native" cattle which are relatively well adapted to tropical and subtropical climates.

Zusammenfassung.

Ein Ueberblick über die wissenschaftliche Literatur, welche sich mit dem Einfluß hoher Lufttemperatur und Luftfeuchtigkeit auf das Vieh befaßt, zeigt einen deutlichen Mangel an befriedigenden experimentellen Daten. Die gegenteilige Einwirkung dieser klimatischen Komponenten auf die Körpertemperatur, die Atmung, die Pulsgeschwindigkeit und die Milchproduktion europäischer Rinderrassen ist eine feststehende Tatsache. Anderseits bestehen noch Widersprüche in den Angaben über den Einfluß der Temperatur auf die Fruchtbarkeit.

Es sind nur wenige Versuche unternommen worden, unter sorgfältig kontrollierten experimentellen Bedingungen, den Einfluß der Temperatur bei konstant bleibender Feuchtigkeit, oder der Feuchtigkeit bei konstant bleibender Temperatur zu studieren. Ueberdies ist die Wirkungsweise dieser meteorologischen Bedingungen in ihrem Zusammenhang mit mikrophysiologischen Prozessen, wie z. B. endokrinen Einflüssen, relativ unbekannt. Bei der Untersuchung des Einflusses hoher Temperaturen auf die Fruchtbarkeit ist es unterlassen worden, das Alter der Tiere und die Einwirkung des Sonnenlichtes mit zu berücksichtigen, zwei Faktoren, die für die Funktion der Geschlechtsdrüsen von großer Bedeutung sind.

Endlich ist es ja nicht nur die Physiologie der Akklimatisation, welche eines eingehenden Studiums bedarf. So wie die Pflanzen haben auch die Tiere ihre spezifischen Mikroklimaten. Unter diesen versteht man aber die klimatischen Verhältnisse der Luftschicht innerhalb der ersten zwei Meter über dem Erdboden, welche vom eigentlichen Makroklima eines Landes wesentlich verschieden sein können; trotzdem werden im allgemeinen bei Akklimatisationsstudien beim Rinde makroklimatische Indices verwendet.

Es ist wahrscheinlich, daß durch wissenschaftliche Züchtung von eingeborenen Zeburindern mit Afrikandern ein hochwertiger Stamm erzielt werden kann, der ebenso produktiv wäre wie europäische Rinder. Desungeachtet würden genauere Untersuchungen über den Einfluß von Temperatur, Feuchtigkeit und andere klimatische Komponenten auf das Vieh wertvolle Ergebnisse zeitigen,

welche die Akklimatisationsbestrebungen erleichtern, die produktive Verwertung des europäischen Rindes erweitern und dazu verhelfen würden, die Produktivität «eingeborener» Rinderrassen, welche an tropische und subtropische Klimaten relativ gut angepaßt sind, zu erproben.

Résumé.

Un coup d'œil sur la littérature scientifique concernant l'influence de la haute température et d'un degré hygrométrique élevé sur le bétail révèle un manque considérable de dates expérimentales satisfaisantes. L'action adverse de ces éléments climatiques sur la température du corps, la respiration, la pulsation et la productivité est un fait établi. D'autre part les dates, concernant l'effet de la température sur la fertilité, sont contradictoires.

Très peu d'essais ont été faits pour étudier dans des conditions expérimentales minutieusement contrôlées l'effet de la température dans une humidité constante ou l'effet de l'humidité dans une température constante. D'autre part, le mode d'action de ces éléments météorologiques en rapport avec des processus microphysiologiques, tel que par exemple l'action endocrine, est relativement inconnu. En étudiant l'effet de la température élevée sur la fertilité, on n'a généralement pas tenu compte de l'âge des animaux ni de l'influence de la lumière du soleil, deux facteurs auxquels la fonction des glandes sexuelles est pourtant intimement liée.

Finalement il ne s'agit pas seulement de la physiologie de l'acclimatation qui demanderait à être étudiée plus à fond. Les animaux aussi bien que les plantes ont leurs microclimats spécifiques. On comprend sous microclimat les conditions qui règnent dans les deux mètres au-dessus du sol et qui peuvent différer considérablement du macroclimat proprement dit d'une région ; cela n'empêche que dans des études sur l'acclimatation du bétail on utilise souvent à tort des indices macroclimatiques.

Il est probable qu'en procédant scientifiquement à l'élevage de zébus indigènes avec des Afrikander, on pourrait obtenir une souche d'animaux supérieurs qui seraient aussi productifs que le bétail européen. Cependant, des investigations plus précises sur l'influence de la température, de l'humidité et d'autres éléments essentiellement climatiques sur le bétail pourraient fournir des données précieuses qui faciliteraient les essais d'acclimatation, étendraient les environs productifs du bétail européen et permettraient d'éprouver la productivité du bétail « indigène » relativement bien adapté au climat tropical et subtropical.