THE INFLUENCE OF TEMPERATURE ON THE PERFORMANCE OF DAIRY CATTLE WITH PARTICULAR REFERENCE TO THE IMPROVEMENT OF DAIRY PRODUCTION IN INDIA.

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CONTENTS.

INTRODUCTION.

Purpose of the study:

In India, although there's a huge population of cattle, the milk production is scanty and the consumption of milk per head of human population is meagre. The importance of milk in maintaining the health of the Indian people who are mostly vegetarian cannot be over-emphasised and in view of this point an urgent need has been felt lately to improve dairy production in India.

In the past European dairy breeds have been imported into India and have been either bred pure or used to grade up the native cattle but such attempts have turned into failure.

In the greater portion of India, excepting at high altitudes on the hills, annual average temperature is high and particularly so during the summer months. It has often been suggested that the high atmospheric temperature has been the cause of degeneration of European cattle in India thus presenting a great obstacle to the improvement of India's dairy production. Very little investigation in this respect has been undertaken in India and there has been a controversy over the importance of high environmental temperature in dairy cattle. The purpose of this dissertation is to study the influence of temperature on the performance of dairy cattle from the observations that have been made in various countries, particularly tropical countries, and to draw a conclusion with regard to the policy of breeding dairy cattle in India in order to increase dairy production. As indicated by the title of the problem this study includes the influence of both high and low environmental temperature.

Definition of the problem:

By the performance of an animal is ordinarily meant the production, may be the milk and butter-fat production of the dairy cow or the wool and mutton production of the sheep. In this study the term has been used in a broader sense to include the important physiological aspects of the dairy cow, e.g. physiological constitution as affected by body temperature, respiration and pulse rates, blood composition, metabolism, food consumption, endocrine glands etc.; growth, reproduction and production. The annual production of a dairy animal as well as her life-time production is dependent on her constitution, growth, reproduction and disease resistance etc. Therefore in this study these aspects of the dairy cow have been dealt with in order to get a true perspective of the influence of temperature on the performance of dairy cattle.

The dissertation has been divided into several sections. The second section deals with the history and origin of temperature (Bos Taurus) and tropical (Bos Indicus often called Zebu or Brahman) cattle and their geographical distribution. In this section it has been attempted to determine whether these two groups of cattle are originally different since they respond differently to the tropical environment, the latter being much more resistant to tropical temperatures than the former. The third section deals with the dairy cattle in India, their economic importance, their production and the problems of cattle improvement. The term dairy cattle in this section has been used to include all cattle since the majority of Indian cattle, excepting a few dairy breeds, are kept for milk production as well as draught. The fourth section deals with the heat regulating mechanism or regulation of body temperature. In this section the general principles of body temperature regulation have been dealt with comprehensively so that the influence of temperature on the dairy cattle can be more fully understood.

In section V the influence of temperature on the performance of dairy cattle - their important physiological functions, growth, fertility, production as well as disease incidence and disease resistance etc. - has been dealt with. Some of these topics e.g. body temperature, respiration and pulse rates, which constitute the vital functions of the animal; fertility and production which are immediately concerned with performance have been discussed in greater detail than the others.

In section VI the effect of temperature on adaptability and in section VII breeding of dairy cattle in the tropics have been dealt with. In these sections the problem of adaptability of dairy cattle in the tropical countries and the breeding methods that have been followed in these countries and the results obtained have been briefly reviewed. In the last section a summary has been given and conclusions have been reached.

No separate section has been allotted to discussion because each section has been discussed where it was deemed necessary. Where anomalous results have been obtained by different workers, the conditions under which the observations were made have been compared in order to trace the cause of the difference and draw conclusion therefrom. All through an attempt has been made to make a comparison, where information was available, between the European cattle and the Zebus in order to bring out the genetical differences between the two groups so that a definite conclusion can be drawn as to whether the dairy cattle of India should be bred from native cattle or from native-European crossing.

11A

HISTORY AND ORIGIN OF THE TEMPERATE AND TROPICAL CATTLE BREEDS (BOS TAURUS AND BOS INDICUS) AND THEIR DISTINGUISHING FEATURES.

The links that indicate the line of descent of our domestic cattle from their wild ancestors are firstly the fossil records and secondly the drawings left by the primitive man.

Disregarding some confusion in early terminology and some persisting disagreement, it is evident that our domesticated cattle came from the wild species of the genus Bos, which is the largest genus of the family Bovidae which, in turn, are the most specialized of the hollow-horned ruminants.

The genus Bos includes the bibovine group, B. gaurus (the gaur); B. frontalis (the gayal); and B. sondaicus (the banteng); the bisontine group, B. grunniens (the yak); B. bonasus (the European bison); and B. bison (the American bison); the bubaline group, B. caffer (the African buffalo); B. bubalis (the Indian buffalo); B. mindorensis (the Mindoro buffalo) and B. depressicornis (the celebes buffalo); and what we commonly call cattle, the taurine group, Bos taurus (European cattle); and Bos indicus (the Zebu cattle) (Rice[1]).

These close relatives of our modern domesticated breeds of cattle form a very interesting and widespread group of mammals. Many of them have become domesticated. Of the bibovine group, the gaur is the largest of the present-day representatives and is found in India, Burma and the Malayan regions. It is largely nocturnal in habit feeding by night and hiding in the jungle by day. The gayal is a semi-domesticated race of the gaur, kept by the tribes of the Assam valley. The banteng is the smallest of this group, found in Burma, Java and Borneo, and resembles the European ox in many respects (Kelley (2)). It provides meat throughout the Far East.

The bisontine group includes the yak of Tibet as well as the European and American bison. The yak inhabits the wild, cold regions of Tibet and Siberia. The yak is the beast of burden in Tibet and it is valued for its milk, its flesh and its fine silky hair. In America, the bison is almost now extinct. However some have been used to cross with European breeds of cattle to give a hybrid known as the Cattelo.

The bubaline group or true buffalo, includes all the semi-hairless Asiatic water-buffaloes and extends through Africa and India to Malaya, Indo-China, and the East Indies. In Egypt and India they are valued for their milk production but many forms are used for draught purposes.

There are in the whole world between six and seven hundred million cattle which are commonly grouped under the one species name of Bos Taurus, although some prefer to give a seperate species name, Bos Indicus, to the Zebu cattle. In the Balkans, Asia Minor, Central Asia, Korea, Formosa and in Eastern and Southern Africa, there is a wide variety of forms intermediate in many respects to the extreme Zebu types and the cattle of Europe.

Concerning the ancestry of European cattle the most commonly mentioned species or sub-species are:-

1. B. longifrons - also called B. brachyceros - which was in Europe as a domesticated animal early in the Neolithic and presumably was domesticated somewhere north of the Alps or in north western Asia.

2. Bos primigenius, the Urus or aurochs, known in Caesar's time as the wild ox of Europe but domesticated long before (perhaps early in the Neolithic), probably south of Alps or

in the Balkans or in Asia Minor.

3. Bos namadicus, Asiatic wild ox, which was spread by tribal migration before 6,000 B.C. to Persia, Mesopotamia, and Egypt and about the same time to India.

4. Leptobos, a long extinct species which was present as wild ox in Asia during the Pleiocene and part of the post Pleiocene period and the females of which were probably hornless, the males having horns between the eye sockets and the top of the head (Lush (3), Kelley (2), Ewart (4)).

Bos primigenius, the longhorned species, survived in the wild state in Europe up to the beginning of the fifteenth century. It is believed that this was probably a variety of B. namadicus, also a longhorned species. It is considered by some that the large longhorned cattle of western Europe are mainly, if not entirely, descended from B. primigenius. Whatever might be the contention, the place of B. primigenius in the ancestry of domestic cattle appears to be well established (Graves and Forhman (5)).

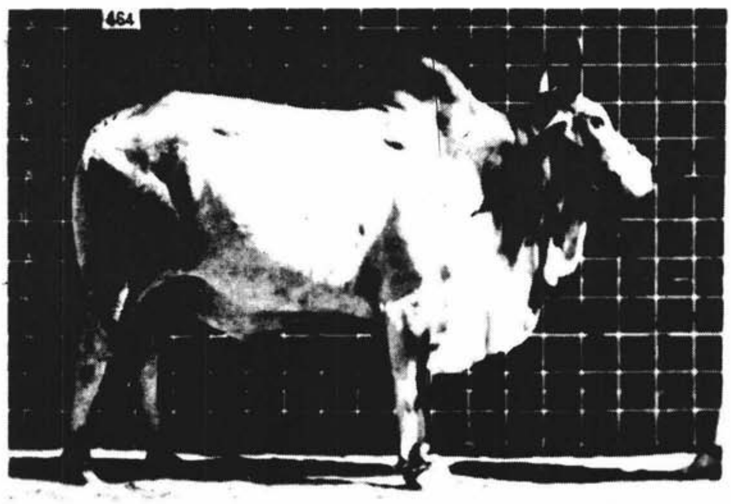
Some confusion persists regarding the origin of the shorthorned breeds. Owen (6) came to the conclusion that shorthorn cattle are descended from the shorthorned species B. longifrons. Osborn (7) states that B. longifron is "the probable ancestor of the small British breeds of shorthorned and hornless cattle." According to one hypothesis B. longifron was derived, about 6,000 B.C., as a dwarfed variety of the longhorned B. namadicus type.

It is considered by many writers that Leptobos was the ancestor of all polled cattle and that the Neolithic herdsmen by crossing hornless females of the Leptobos race with horned bulls and interbreeding the first crosses created new breeds characterised by the absence of horns in both species. However many others still believe that polled cattle like others are descended from horned ancestors and

Prehistoric and existing
Indian cattle.

c. Lyre-horned Malvi bull, *ca.* 3000 B.C.

Lyre-horned Malvi bull, 3,000 B.C.
Bull on seal from Mohan-jo-dara.



d. Malvi Bull

Malvi Bull.
PLATE 1.

that the loss of horns has resulted from what may be termed a "spontaneous organic change," having occurred in the misty ages of the past (Ewart[4]). If this is true it would indicate a common origin for all domestic European breeds, although most writers believe that they came from two or more sources.

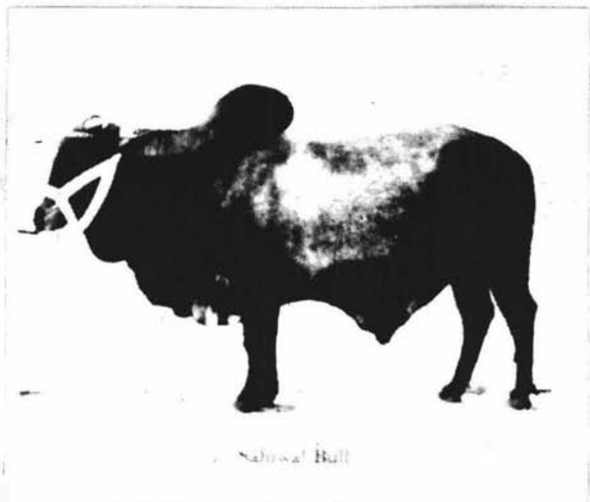
It appears that the Bos Indicus or the Zebu cattle originated from the B. namadicus or the Asiatic wild ox but whether there was any crossing with B. primigenius or B. longifron is not known.

Excavations at Mohan-jo-dara have disclosed, in this Indus valley civilization, animal remains dating from 3,000 B. C.

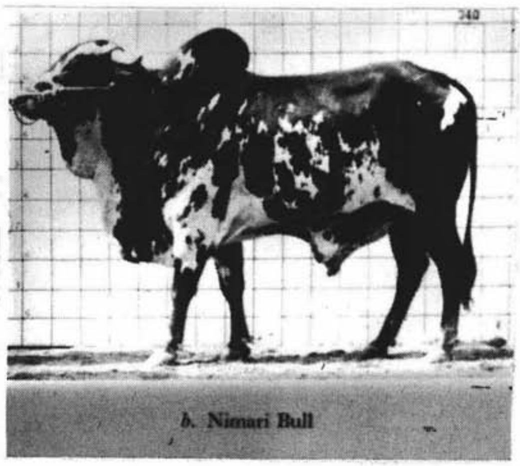
These remains indicate that the same type of Zebu which is found in India today was in use at the time of the ancient Indus valley civilization (see plate 1). Shirlaw[8] points out that there were actually two types of cattle in existence at the time of this civilization, "a massive large-horned humped form and a smaller form with short horns which may possibly have been humpless." Both the humped and the humpless types have been found in the excavations. According to Epsein[9] the shorthorned Zebu is the result of interbreeding in India between B. longifrons and the lateral-horned Zebu. The only evidence that the former ever reached India is the possibly humpless variety recovered from upper strata of the Indus valley and no specimens of the lateral-horned Zebu have yet been found. The African cattle are believed to originate from a mixture of B. primigenius with Zebus.

Ware[10] states that the animal on the seal (plate 1) resembles more closely the lyre-horned Malvi breed of India and the Peulhe or Gobra lyre-horned Zebus of West Africa. He also sees great similarity between the Kankrej breed of India and the Fullani cattle of Africa.

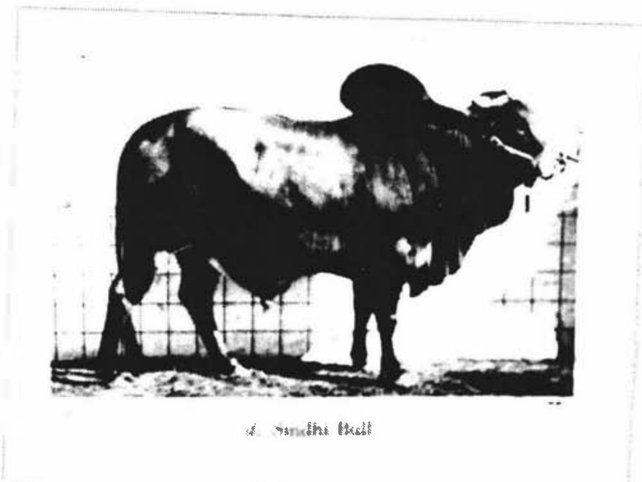
INDIAN CATTLE.
(From Ware, F. (10))



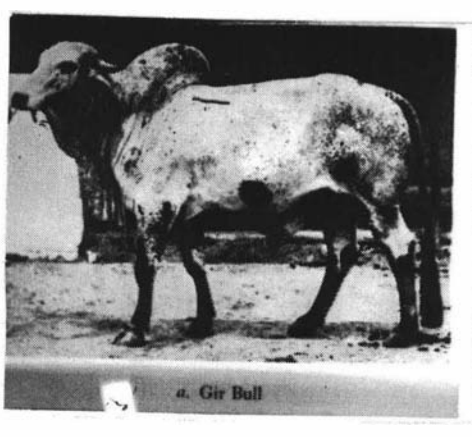
Sahiwal Bull.



Nimari Bull.



SINDHI Bull.



Gir Bull.

PLATE 2.

The literature on this subject of origin of cattle is rather involved and this reveals the indeterminable nature of the subject. From what has been said before it appears that the origin of both European (Bos Taurus) and tropical (Bos Indicus) types of cattle can be traced to the common ancestor or ancestors in the remote past. The point that should be emphasised is that no existing breed or strain of cattle should be regarded as having an independent creation; each, throughout very many centuries, has resulted from continuous specializations by members of pre-existent stocks.

The European and the tropical cattle have been subjected to different types of environment from time immemorial and through selection, natural and artificial, they have evolved as two different genetic types, each adapted to its particular environment temperate or tropical.

Distinguishing features:

The general appearance of the more important British and European beef and dairy breeds is well known. The characteristics of the Zebu type is shown in the plates (1 and 2). The distinguishing features (Kelley[2][11]) in each type can be tabulated as follows:-

Character	European cattle (British breeds)	Indian cattle (typical Zebu)
Hump	No hump at wither	Hump which generally descends abruptly to the wither.
Ears	Usually carried at right angles to the head, comparatively short and rounded at the tips.	Long and drooping. Some breeds are lop-eared. When shorter the ear is pointed.
Skin	Generally stretched relatively tight over body. Thick in texture.	Loose and pendulous below neck, at brisket, umbilicus and penis. Thinner texture but dense. Area greater than European type on same sized beast.
Back line	Characteristically straight.	High at shoulder where the hump is attached, low immediately behind rising again to a peak between hipbones, and declining steeply to the tail.
Hip bones	Wide and outstanding.	Relatively narrow and not prominent.
Ribs	Typically well sprung with round chest.	Ribs straighter, chest more nearly oval, that is relatively deep and narrow.
Udder	Long flat-bottomed, running well back. Teats set squarely and widely spaced.	Generally opposite, but a type of udder similar to that of many Friesian cows is not uncommon.
Hair	Long and animals often rough coated.	Short and sleek, animals generally smooth coated.
Horns	In general short	Usually long.
Colour	Hair and skin similar white spotting. common.	The skin black or ebony, the hair white, grey, red or black. Most breeds are self-coloured.

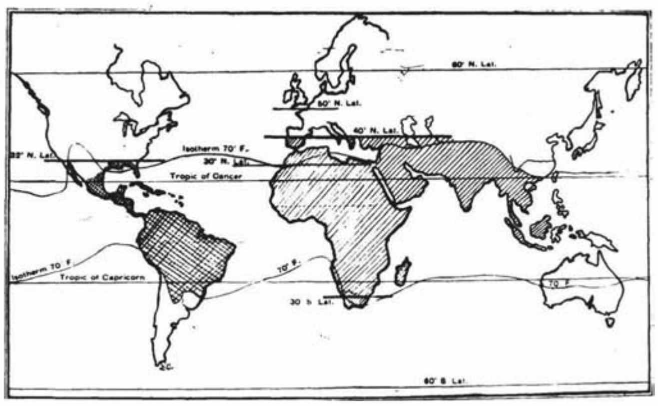


FIG. 1.

World map showing natural and artificial distribution of tropical type (Zebu) cattle, certain parallels of latitude, and the isotherm for 70°F.
Single hatching natural;
Double hatching, a tificial.

11B.

GENERAL DISTRIBUTION OF DAIRY CATTLE IN THE WORLD - WITH AN OUTLINE MAP SHOWING TROPICAL AND TEMPERATE ISOTHERMS.

Bos Taurus cattle are found in the temperate countries and the Bos Indicus cattle are found close to or within the tropics. These two classes of cattle not only constitute the indiginous breeds of their respective regions but their natural habitats extended, in course of latter-day development in stocking with cattle, in other countries of similar climates such as North and South America, Australia, and New Zealand, the geographical isolation of which had prevented the migration of stock in a more natural way.

The distribution, natural and artificial, of the relatively longhaired and unpigmented-skinned Bos Taurus and the short-haired pigmented skinned Bos Indicus are shown in the outline map (Fig. 1). Broadly, the Zebus are found between 32° N and 32° S latitudes and within the isotherms for 70° F. Beyond this region, i. e. in the region of temperate climate are found the Taurus cattle. The acclimatization of the Taurus cattle in those parts of the tropics with an altitude of 4,000 feet or so has been relatively successful, but, generally the nearer the Equator the more pronounced are the Zebu characters, and the less successful is the acclimatization of the Taurus.

In Europe, countries such as Spain, Italy, Greece and on to Mesopotamia, all cut by the 40° parallel of latitude, have short-haired, Zebu-like cattle, though normally without humps.

III.

DAIRY CATTLE IN INDIA.

A. ECONOMIC IMPORTANCE AND STATUS OF CATTLE IN INDIA:

India is a vast agricultural country with a human population of 400 million people, 90% of whom are rural in habit and residence and live on agriculture. India's farmers and their holdings are very small and scattered, of 2 - 3 acres in size on the average. So use of machinery for tilling of the soil is practically out of the question and the only available source of power is the bullock. Again most of the people are vegetarian, milk and milk products being the main source of animal protein in their diets. The social and economic importance of cattle is, therefore, self-evident

1. Importance of Cattle in Indian Agriculture:

The Marquess of Linlithgow, the former Viceroy of India and previously the Chairman of the Royal Commission on Agriculture in India observed that "the cow and the working bullock bear on their patient backs the whole structure of Indian Agriculture." This remark puts in a nutshell the great importance of cattle to Indian economy.

Numerically India possesses the largest population of the world - 200 million cattle, about one-third of the world cattle population (U. S. Year-book[12]). Owing to adverse climatic and economic conditions the productive value of the cattle industry of India is not commensurate with its size. Still this is an important industry in India. The actual and potential value of India's cattle industry is huge even in the present undeveloped state.

The annual value of milk and milk products is by a conservative estimate not less than 300 crores of rupees or £225 million (sterling). This is roughly equivalent to the value of India's total output of rice and 3 - 4 times the value of wheat output (Wright).

The output of hides and skins, of which India is the largest exporter in the British Empire, is annually worth about 40 crores of rupees or £30 million (sterling). The trade in hides and skins which represent only a minor by-product of cattle industry has a greater monetary value than the total Indian output of sugar. Incidentally India is the largest sugar producing and exporting country in the world.

Indian cattle used to be exported to America, Africa, Australia, Phillipines and other tropical countries, and the annual export in 1937-38 reached nearly 2,000 animals (14). However this is a small source of income from cattle industry.

It is, however, in relation to the agriculture of the country, that the unique value of cattle becomes apparent. The bullock is almost the only source of power available for carrying out the various agricultural operations extending over an area of 300 million acres of cultivation and acts as the major road transport animal. "Without ox no cultivation could be possible; without ox no produce could be transported." (Wright (13)). The cash value of cattle labour in India has been estimated at 400 crores of rupees or £300 million (sterling).

Another indirect source of income attributable to cattle is the manure which may be used for increasing fertility of the soil. The cash value of manure is estimated at 270 crores of rupees or £200 million.

Therefore the total cash value of cattle industry in India, including the milk and milk products, is estimated at 1,000 crores of rupees or 750 million pounds and this contributes about half of the total agricultural income of the country which has been estimated at 2,000 crores of rupees or 1,500 million pounds (Ware (10)).

This shows the actual value and the magnitude of the cattle industry in India. The potential value of cattle as a means of raising the level of soil fertility by way of compost making etc. and thus increasing the output of both cash and food crops, and also as a means of increasing the milk production of the country by suitable breeding, feeding and management, and thus adding to the health and wealth of the nation, is incalculable.

2. Importance of Cattle from Nutritional Point of Indian People - Need for Increased Consumption of Milk:

Milk is the most perfect single food known. The food value of milk is borne out by the "Milk in Schools" schemes in Britain, New Zealand and other countries and need not be stressed. It contains, in an easily digestible form, all the materials essential for growth and maintenance of life. It is particularly rich in protein of high biological value, while milk fat is a great source of energy and is the most palatable of animals fats. Milk also contains sugar and minerals in highly available forms. It is rich in vitamins, except that vitamin C content is limited. Considering these special properties it is no wonder that milk is so important a food stuff for the adults and still more so for children whose bodies are still developing.

Although the high food value of milk is appreciated everywhere and by everybody, yet there are many countries such as India where this coveted food is not within the reach of the majority of the people and the consumption per head is very low.

India produces about 6,400 million gallons of milk and stands second in volume of milk production, U.S.A. coming first, but this output of milk is not much compared to the large human population and as a result the per capita consumption of milk per day - milk products converted to milk - is miserably low, only about 7 ozs. (Milk Marketing Report (15)) Many persons including children have to go completely without milk.

A highly industrialized country like Britain is able to import sufficient milk products to raise the consumptic but India, being predominantly a rural country, cannot afford to do so. Average per capita income of Indian people is very small and onlь people of the higher income group can afford for higher consumption of milk.

In the good dairying tracts like the Punjab and Sind the per capita consumption of milk isthe highest, 15 - 18 ozs. and the people in these provinces are the healthiest in India whereas in some other provinces, Bengal, Assam and C.P., the per capita consumption per day is not more than 2 - 3 ozs. The highly perishable nature of milk, the assembling and transport difficulties, the high temperature etc. make interprovincial transferance or transferance from rural to urban areas, of liquid milk impracticable and so the surplus milk is converted to ghee which has a high keeping quality.

It is interesting to note that in comparison to meagre consumption of 7 ozs. in India, the consumption in Canada is about 57 ozs. per day, in New Zealand 56 ozs., Australia 44 ozs. and Great Britain 41 ozs. (Wright (13)). It is also noticed that in these countries, on an average, about 40% of the milk consumption is drunk in the fluid form. In India only about a quarter of the production is consumed that way (Wright).

In India most of the population subsist on a vegetarian diet and milk is, in fact, the only available source of "first class" protein, while it will supply at the same time minerals and vitamins.

According to European standard about 10 - 15% of the daily intake of energy should be derived from protein. This means an intake of about 100 gms. of protein per day, and of this about one-third should be first class protein. The Indian authorities, however, put the requirement for an average Indian at 65 gms. of total protein, of which about one-quarter should be of animal origin (Wright). On this basis and taking milk as the only source of first class protein an European should consume 35 ozs. and an Indian about 15 ozs. of milk a day. Indian requirement is much smaller but still it needs double the quantity of milk available at present in the country.

The necessity for increasing milk consumption is not only to supply first class protein but also to supply a protective food. With a vegetarian diet derived from a very limited variety of food stuffs, there is a serious risk of a deficiency of both minerals and vitamins and particularly in so far as the nutrition of the growing children is concerned, the situation is one of a miserable plight. The most important task for a social reformer, who wants to see a healthy nation in India, is to increase India's milk production. Such an increase in milk production, however, would fail to achieve its object unless the income level of the population could be raised because it is the poor people who constitute the majority and who go without milk although they are the real producers of milk.

From the point of view of nutrition of people, therefore, the importance of dairy cattle in India is immensely great.

3. Some Important Indian Dairy Breeds:

The Indian cattle are Bos Indicus or the Zebu, a humped animal, considered to be a different species from the European cattle, Bos Taurus. That the Zebus are genetically different from the Bos Taurus has been repeatedly proved by the scientists who have shown that in the tropics only cattle with Zebu blood can thrive. This point will be made clear in the subsequent sections.

In India cattle serve the double purpose of supplying draught and milk whereas in European countries the dual purpose animal is for meat and milk. The majority of cattle in India are scrub cattle not belonging to any distinct breeds. However, the cattle belonging to different provinces have their distinguishing characteristics as regard size, colour and capability, and recently the cattle of India have been enumerated into 28 breeds, in addition to seven breeds of buffaloes. Most of these breeds are draught or dual purpose breeds. A few dairy breeds with high milking potentialities have also been located and they are mainly found in the northern and north-western parts of India. One view is held that these milking breeds of cattle were originally brought by the Aryans themsleves when they migrated to India about 2,000 - 3,000 B.C. Another view is that these breeds are of indigenous origin (Dasgupta [16]). It is a matter of research to find out the origin of Indian cattle and in this line very little has been done.

Olver [17] classified Indian cattle into five well marked groups as follows:-

Group 1. Lyre-horned grey cattle with wide forehead, prominant orbital arches, face flat, represented by dual purpose breeds such as Kankrej, Malvi and possibly Tharparker, found in north India.

Group 11. Shorthorned, white or light grey, narrow-faced cattle of northern and central India, represented by some draught and dual purpose breeds such as Bhagnari, Nagori, Hariana, Krishna Valley and Ongole breeds.

FIG. 3.

Map of India showing provincial areas.

Group 111. Animals lethargic, usually spotted red and white or brown and white, with prominent forehead, lateral and often curly-horned, represented by prominent milch breeds e.g. Sahiwal, Gir and possibly Sindhi.

Group 1V. Medium sized, compact draught-type animals, usually grey, long pointed horns, represented by the Hallikar, Amritmahal, Khillari, Kangayam breeds.

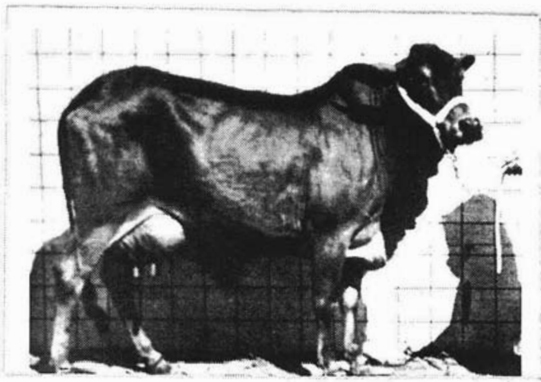
Group V. Small red or black, shorthorned cattle, represented by the hill type cattle, possibly of ancient India, Lohani, Afghan and Sri breeds. (For distribution of breeds see figs. 3 and 4).

Breeds with potentialities of milk production (Ware[10]; Kothavala[18]).

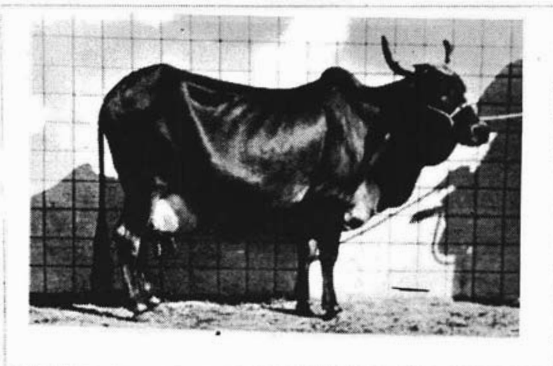
SAHIWAL: This is the premier milch breed of India. These are purely dairy cattle, which in the past were raised in large numbers in the dry central and southern areas of the Punjab. The animals are medium sized. The bullocks are too slow and lethargic for draught purpose and this breed lost its importance due to its failure to meet the agricultura requirements of the country. Recently their milking potentialities have been realized and the cows have yielded large amounts of milk on various Government farms. Pedigree herds of this breed are maintained on many farms. Three outstanding Sahiwal herds are kept at the Government farms at New Delhi, Lyalpur and Ferozepur. These breeds were established about thirty years ago and since then the average milk yield has increased from 5 - 6 lbs. to 17 - 20 lbs. daily The average lactation started with 2,000 lbs. of milk and it has increased to more than 7,000 lbs. Yields up to 13,000 - 14,000 lbs. of milk in about 308 days of lactation have been produced by two pedigree cows. The average annual milk yield of Sahiwal cows on a well maintained herd

FIG. 4.

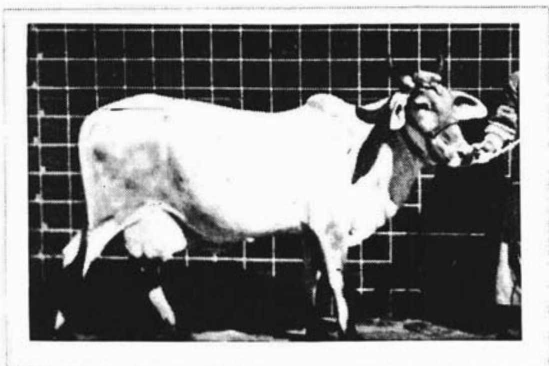
Map of India showing distribution of breeds. (Dasgupta(16)).



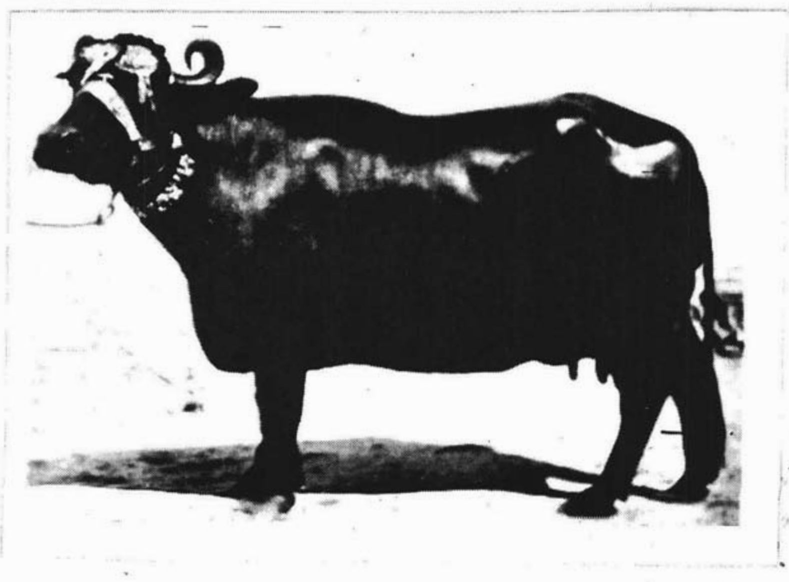
Sahiwal cow.



Sindhi cow.



Tharparker cow.



Murrah buffalo cow.

PLATE 3.

is about 5,000 - 6,000 lbs. The plate (3) shows the photograph of a well bred Sahiwal cow.

SINDHI: The home of this breed is the country around Karachi. The correct colour of this breed is a deep dark red but varies from dun yellow to almost dark brown. The bull, as a rule, runs to a much darker red than the cow. The Sindhis are among the most efficient milch cattle of India. The Sindhis are of medium size and in shape they are compact with the true wedge shape in the case of the female. The average mature female, weighs about 750 lbs. and the male about 925 lbs. The Sindhi cow is particularly docile and is a distinctive dairy animal. They can thrive under varying conditions of soil and climate and it is, therefore, that they are used for grading up local cattle in many areas. The bullocks are small and efficient draught animals.

Sindhi cows are high milk yielders and are considered to be the most economical milk producers amongst the Indian breeds of cattle. Yields as high as 12,000 lbs. of milk in a lactation of little over 300 days have been recorded but the average lactation yield may be taken as 4,000 lbs. of milk.

THARPARKER: These are the cattle of the arid semi-desert tracts of south-west Sind and are grey-white in colour. Typical Tharparkers are medium-sized dual-purpose animals. This breed is proving to be one of the best milch breeds of India, while the bullocks are useful for plough or carting. They are also reputed to thrive on scanty fodder. These points of excellence are making them popular. Cows on the Government farms have yielded up to 9,000 lbs. of milk in a lactation of 308 days. The average production on well managed farms may be taken as 4,000 - 5,000 lbs. of milk.

Other dual purpose breeds producing good milkers and good bullocks are Hariana, Gir, Kankrej. The average milk yields of these breeds in a lactation of ten months may be taken as 3,000 - 4,000 lbs. and individual records as high as 7,000 in 325 days of lactation have been obtained.

Bulls of Hariana breed are being extensively and successfully used for grading up the cattle in Bengal. High grade cows are good milkers and the bullocks are good draught animals.

INDIAN BUFFALO: Picture on milk production in India would be incomplete without mentioning the capabilities of Indian buffalo. Of the different breeds of buffaloes in India Murrah has been the most developed for milk production. On the average a she-buffalo will produce as much as or even more than the average cow of the best dairy breed in India. The average butterfat content of buffalo milk (7%) is much higher than that of the cow's milk (4 - 5%).

The high levels of milk production already reached by the breeds mentioned above show the potentialities of Indian cattle as milk producers. The Sahiwal on the Government farms under well managed conditions has reached in thirty years a level of milking performance which is in no way inferior to that of any foreign breed.

4. Production of milk and its quality:

India's milk production has been estimated at 6,400 million gallons of milk. Of this 28% is consumed as fluid (liquid milk) and 57% is converted to ghee and the rest (15%) to other products such as Khoa, curd (dahi), butter, ice-cream, cream etc.

Cows and buffaloes constitute the chief source of milk supply. Goats also contribute a small proportion. According to the cattle census of 1940, India possesses 49 million milking cows, 21.4 million milking she-buffaloes and 9.8 million milking goats.

The proportions of milk production by these animals are as follows:-

	Cows	She-buffaloes	Goats
Milking animals (million)	49	21.4	9.8
% of the total animals	61	26.8	12.2
% of total production	46	51	3

So although the cows are numerically more than double the buffaloes the latter contribute more to the production than the former. Considering this some people have stated that more attention should be paid to the buffaloes than to the cows in future but that is an erroneous conclusion because the importance of cattle in India is not only as producers of milk but also as draft animals.

From the milk production point of view, some breeds of India such as Sahiwai, Sindhi, Tharparker, Hariana, Gir etc. which have been mentioned before, are good but the average cow is a poor producer.

Although India has as many milch cattle as Europe including Russia, the production of milk is only a fifth of that of Europe. Compared with India, Canada produces 25% of India's total milk production but with only about 6% cattle.

Considering the daily production per head of population, New Zealand produces 244 ozs., Denmark 148 ozs., Australia 69 ozs., Canada 66 ozs., Great Britain 14 ozs. and India only 7 - 8 ozs. (Wright[13]).

The average annual yield per cow, on all India basis, is only 487 lbs. and per she-buffalo 1,229 lbs. In certain parts of the Punjab which is the best dairying province in India, she-buffaloes yield on the average 2,500 lbs. of milk (162 lbs. b. f.) and the cows 1,445 lbs. of milk (72 lbs. b. f.) per annum (Milk Marketing Report[15]).

The above yields are poor as compared with those in foreign countries. Mainly poor feeding and management are responsible for poor yield of the Indian cows because it has been found that the village cows when brought to the Government farms produce 60% more milk in subsequent lactation and that the first progeny of these cows show a further increase of 10 to 15% in their milk yields above their dams (Milk Marketing Report (15)). Therefore, the target of India's milk production - increasing it twofold in order to reach the required per capita consumption of 16 ozs - is not at all impossible to attain if the feeding and management conditions are improved along with breeding. The Sahiwal, the best Indian dairy animal is capable of taking a position in line with the best milkers of the world. She has shown in several instances a record of 14,000 lbs. of milk in a normal lactation of about 300 days.

Quality of Milk:

The milk of Indian cows and she-buffaloes is much richer than that obtained in countries abroad. Cow's milk tests 4.5 - 5.5% according to different breeds and buffalo milk contains 6.5 to 8% fat. Cow's milk contains 8.9% S.N.F. and 13.7% total solids.

B. PROBLEMS OF CATTLE IMPROVEMENT IN INDIA:

The problems of cattle improvement in India are manifold. Apart from the unfavourable climatic conditions - high temperature and humidity and uneven distribution of rainfall most of which occurs during the monsoon (June - September) - there are some special problems in India.

Firstly, the number of cattle in India is far too great for the fodder resources of the country. The area of cultivated land available per head of bovine population is 1.8 acres as compared with 3.4 acres in Great Britain, 4.5 in New Zealand, 31.4 in Canada and 24.9 in U.S.A. The Royal Commission on Agriculture estimated that for every 100 acres of nett sown area there are 21 acres fallow, 92 acres of grazing, and 20 bullocks, 17 cows, 16 other cattle, 3 male buffaloes, 3 female buffaloes, 5 young buffaloes and 27 sheep and goats. This clearly shows the pressure on land and the acute nature of the problem (Ware[10]).

Secondly, cattle breeding is mostly in the hands of small farmers who are poor and illiterate. According to a village enquiry (19) in which an intensive survey of selected breeding tracts was made, the average size of holdings in different parts of the country varies between 7 and 23 acres. These small areas have to support 6 - 9 persons and 3 - 7 head of cattle each. Such small farmers are naturally unable to invest capital in pedigree stud animals and there has been a tendency all over India to rely on quantity rather than quality, as an insurance against such cattle plagues as rinderpest and haemorrhagic septicemia which break out in the country periodically and carry off large number of animals.

Thirdly, the cow is a sacred animal to the Hindus. According to the Vedas, the religious book of Hindus, the cow must not be slaughtered, but allowed to live after her productive period is over and die a natural death. This is a most important barrier to the improvement of cattle in India and involves a great economic loss to the country. In many parts of India these different factors have created a vicious circle. Not only is the overstocking a cause of shortage of animal feed and indirectly human food as well but also is one of the major causes of soil erosion because the last bit of the shrub growth is grazed by the animals.

1. Feeding:

The areas in which the better and poorer types of cattle are found can be correlated with the climatic conditions and the type of cultivation. Good breeds of cattle are confined to comparatively dry areas such as Sind, the Punjab, Rajputana States, Kathiwar (see fig. 3) and such parts of other provinces where similar conditions exist. Pasture in these areas may be of good quality but is often scarce. Conversely in tracts with a humid climate, which are subject to heavy rainfall or are provided with ample irrigation water a very poor type of cattle is found in spite of the availability of some grazing. In the rice growing tracts and flooded areas of Assam, Bengal, Bihar, Orissa, Madras, Travancore etc. where the conditions are very humid, cattle are generally found to be greatly deteriorated, both as regards their physical development and capacity for work.

Apart from the climatic factors on which very little investigation has been made nutrition is the most important single factor responsible for the deterioration and the poor production of the village cattle. The Royal Commission on Agriculture in India stated "no substantial improvement in the way of breeding is possible until the cattle can be better fed." No doubt the slow rate of growth, the late maturity and the long dry periods of Indian cattle kept under village conditions are due mainly to the poor nutrition. It is quite usual for a cow to drop her first calf at 4 to 5 years of age, and to have calving intervals of 600 days. That this is not hereditary but nutritional has been proved by the experiments at Pusa (20) where the heifers took the bull at fourteen months of age and calved at the age of twenty three months and the yearling bulls started service at the age of 1½ years as compared with 3 - 3½ years in case of ordinary bulls. The production of the early matured cows was quite up to the standard.

Cattle feed in India may be divided into (a) roughages and (b) concentrates. The former includes fodder crops, the straws of cultivated crops such as rice, wheat, barley and millets etc. and grasses. Concentrates include oil-cakes, cotton seed, grain, cereal husks and bran etc.

The total quantity of available feeding stuffs in India, consisting of dry fodder, green fodder and concentrates, has been estimated at 215 million tons. This amount of feed for more than 215 million of cattle population including buffaloes, goats and sheep works out at 6 lbs. per head per day, about half of which is green (Dasgupta (21)). This daily ration converted to dry matter would come to only 4 lbs. per day.

It has been said that even the very small cows as found in Bengal would require 8 - 10 lbs. of D.M. per day. Working bullocks, buffaloes and milking cows require very much larger quantities. This gives some idea about the hopeless conditions of the nutrition of Indian cattle.

The amount of grazing available is very much insufficient as regards both yield and acreage. The problem of feeding human mouths is an immediate one and, therefore, the grass lands, which can produce crops are brought under the plough whenever practicable. The grazing lands that are available are common and continuously grazed without following any rotational system. The result is that within a short time there is hardly any green leaf left on the ground which becomes suitable only for the exercise, of which the wretched animals apparently need very little.

Another difficulty is that, the rainfalls being seasonal, grass is available only for a few months in the year; for the rest of the year there is little grass to be had. Investigations should be made regarding the possibility of improving the grazing in India and the system of rotational grazing must be introduced wherever grazing is available or can be developed. The question of making more use of the available forest grass as hay and the growing of the trees of the fodder species in the minor forest where much of the grazing occurs should be investigated.

Dry fodder such as rice straw and wheat straw are very poor feed for milking cattle unless balanced with concentrates and other feeding stuffs. Rice and wheat straws are very poor in protein and carotene contents, deficient in minerals and have a wide nutritive ratio 1:40. Therefore rations for dairy cattle should be supplemented by minerals. Grasses such as Sudan grass, guinea grass, elephant grass and the spear grass which are grown in parts of India have nutritive ratios between 1:10 and 1:12 (Wright[13]) and should be more widely used. Leguminous fodders such as Berseem (Egyptian clover), and lucerne (alfalfa) which have been successfully grown in India are ideal for milk production (N.R. = 1:4 to 1:6) and are of outstanding importance to Indian agriculture by virtue of their ability to increase soil fertility. Surplus fodder, when available, should be conserved as hay and silage.

Concentrates such as linseed, cottonseed and earthnut cakes, are very rich in protein and have N.R. between 1:1 and 1:3. Large quantities of concentrates are exported annually from India. If this is stopped it would result in a considerable increase in the available quantity of digestible crude proteins.

There is little use in attempting to increase the production of milk in India unless the nutrition of the cattle is improved. At present in India there are too many cattle drawing on the country's resources. If the nutrition of these animals can be improved, the cows will produce more milk, the bullocks will till more land per head, so less number will be required and they will give better return.

2. Breeding:

The majority of the cattle maintained in the villages are of mixed breed and are nondescript in type. In the villages no breeding policy is followed and breeding is absolutely indiscriminate except for a few professional breeders near the forest areas, who practice a fair amount of selection in the breeding of their herd. These professional breeders send their cattle to the forest areas where they are kept inside pens and are allowed to graze with the herds headed by selected breeding bulls.

The breeding policy for cattle in India refers to the early trials on the Military Dairy Farms and some Agricultural College Farms to improve the milk yield of the indigenous cattle by crossing with European breeds such as Friesian, Ayrshire, Shorthorn and Jersey. The immediate results of the crossing with European cattle were certainly striking. In the first cross, the production increased 50% but subsequently with further increase in the percentage of European blood, the grade animals became unsuited to Indian climatic conditions, their constitution broke down, they became highly susceptible to disease and their production fell. So this policy of grading up Indian cattle with European breeds has been abandoned. In the opinion of Colonel Watson (22) who was in charge of Military Dairy Farms in India for many years, the general adoption of such a cross-breeding policy with European cattle to improve the milk yields of country stock "would be fatal to the development of sound dairying in India."

According to Wright (13) the best solution of the problem lies in the selection of milking strains from amongst the Indian cattle.

The experiments on the Government farms where the milk yields of the Indian breeds have more than trebled in twenty years with a herd average of more than 7,000 lbs. show that the strains of cattle with high milking potentialities are not lacking in India and that these strains can be developed up to the standard of the best European breeds by proper feeding, breeding and management.

In view of these points the Government has recently concentrated on the gradual grading up of the country cattle with the bulls of selected breeds suited to different localities. In order to achieve this end the Central and Provincial Governments are maintaining stud farms in different areas. In Bengal the local cattle are being graded up with bulls of Hariana breed, imported from the Punjab which is an excellent dual purpose (milk and draught) breed and which has well adapted to the local conditions. Several stud farms located in different parts supply the stud bulls to the villagers. In the policy of cattle improvement by breeding in India the following points have been laid down (23) :-

1. The removal or castration of all the scrub bulls found in a particular area.
2. The supply of the requisite number of bulls of an approved breed for the area.
3. The replacement of these bulls at regular intervals.
4. The maintenance of a systematic service record of the bulls and their progeny if possible.

The total number of available approved bulls is still grossly inadequate. However steps have been taken in the right direction and some improvement has taken place during the last few years.

The need of a large number of approved bulls can be met to a certain extent by the introduction of artificial insemination but the feasibility of its application to a large number of scattered animals in India has to be investigated.

An essential step, according to Wright, in developing high milking strains of Indian breeds of cattle is the establishment of herd books and of a system of milk recording. Preliminary steps have been taken in this direction on Government Stud Farms. Progeny testing must be carried out at these farms to locate the best bulls and the best utilization of the proven bulls should be made. The late maturity of Indian cattle may appear to be a great obstacle in the way of improvement of dairy cattle but it has been shown in the early maturity trials that late maturity is not inherent in the Indian cattle and can be easily overcome by better feeding, breeding and management.

In the long term policy of improvement of dairy cattle, buffalo which contributes greatly to India's dairy production, can probably be ruled out. It is doubtful whether the she-buffalo is as good and economic a producer as the dairy cow under well managed conditions. On the Military Dairy Farms it has been found that under good conditions of feeding and management the ordinary Sahiwal will produce as much as a buffalo while high milking strains of the Sahiwal will produce half as much again. Buffalo is a much larger animal than the cow, and her maintenance requirement is much higher and hence she cannot be as efficient as the cow when she is producing as much as or less than the cow.

3. Management:

The Indian cattle are very much neglected. Again the cow and the female-calf are the most neglected because she is valued mainly as a breeder of bullocks. The cow and the heifer are ordinarily left to eke out their living from what they can get from grazing and from the leavings of the bullocks. Broadly, it would be true to say that if there is any fodder available after the draught cattle have been fed, the gow gets it, or shares it with the young stock, for the rest she is left to find food where she can. When the cow provides some milk for the household as well as for her calf, cultivators try to spare her a couple of pounds of a mixture of cotton-seed bran or oil cake or pulse, but when she is dry, the ration is withdrawn and she is turned out to find a living for herself from grazing on some fallow lands carrying very little green grass.

In short the management of Indian cattle is deplorable - it's not wonder considering the deplorable conditions of Indian cultivators themselves - and they are exposed to the ravages of weather, rain, storms etc.

In a country which has an exacting climate, high humidity and high temperature, as experienced, during the greater part of the year, in the plains where the great majority of the cattle are located, the question of management is extremely important. If a plan for intensive milk production is to be inaugurated, management becomes more important for the economic performance of the dairy cattle. Attempts are being made to improve the milk production of the Indian cattle but such attempts will turn out fruitless unless the feeding and management conditions are improved.

It has been shown (Wright [13]) on the Military Dairy Farms that the preservation of constitution is a definite limiting factor in the improvement of milk yield beyond a certain limit. If high-yielding cows are poorly fed and managed, their constitution breaks down under the pressure of high milk yields.

The importance of good feeding and management for increasing milk production is also evident from the fact that some of the serious defects of Indian cows e.g. late maturity, long service and dry periods, can be overcome, as has been done at the Imperial Agricultural Research Institute, under well managed conditions.

There are other points of managements that should be attended to in order to increase the efficiency of dairy cattle in India. In many places it is necessary to arrange for an adequate supply of water and, as a measure against disease, to construct water troughs. Protection, especially to young animals against climatic extremes is necessary if stock is to be managed at an optimum level. Where milk is to be produced under village conditions, sheds should be provided so that the quality of milk can be maintained. In the urban areas, the cows should be housed in buildings and kept under hygienic conditions. The keeping of cows and buffaloes in the cities and allowing them to wander about in the streets is a bad practice altogether and should be stopped. The policy of extracting as much milk as possible from a cow in one lactation by evil means such as phooka, a process of blowing air into the uterus, which is practised daily at the time of milking by herdsmen in the cities, and then sending the wretched animal to the butcher when dry is absolutely anti-national and deserves severe treatment.

4. Disease:

Disease has been one of the greatest limiting factors in cattle improvement in India.

Diseases, nutritional and contagious, take a heavy toll of cattle every year. The importance of infectious and contagious diseases overshadows the importance of all other diseases put together. When an epidemic occurs it carried away thousands of animals. No reliable statistics as regards the annual mortality of the cattle is available but from the fragmentary information reported to the veterinary department, the total mortality from epidemic diseases is about half a million every year. Of this total, one disease only, rinderpest, accounts for 60%. Other infectious diseases next in importance to rinderpest, are haemorrhagic septicaemia, black quarter, authra and foot--and-mouth diseases. The mortality from the foot-and-mouth disease is very small - only 4 to 8% of affected cattle die - but this disease ruins the constitution of the animals that survive and the economic loss is enormous.

The veterinary service which is entirely maintained by the Government or public bodies like municipalities and District Boards, is very meagre, like a drop in the ocean, considering the largeness of India's cattle population. Private practitioners are rare. This state of things is responsible for much suffering amongst the cattle. Fever, pneumonia, dysentery, diarrhoea, tuberculosis, para-tuberculosis, take their toll. Surgical cases often occur; wounds, cuts, burns, blisters, ulcers and sores, fractures and dislocations are rarely attended to and these do cause a lot of suffering.

In a country like India where the cultivation of land and transport of goods - hence the whole structure of agriculture - depend upon the well-being of bullocks, the economic loss due to cattle diseases is inestimable.

Under-nutrition or malnutrition diseases are common in India. Mineral deficiency is the cause of pica and osteomalacia in Madras and Hyderabad, and the stunted growth, low production, high mortality and sterility over the larger part of India (Kaura[24]). The disease known as the "blindness in calves" which is usually associated with a nonspecific form of abortion in cattle has been shown to be due to malnutrition (Kaura).

Sen and Seshan[25] reported that the "blindness in calves" and high incidence of sterility among cattle are mainly due to the deficiency of vitamin A and carotene in the ration that is usually devoid of green grass and green fodder. There is no doubt that the poor nutrition of the animals predisposes them to various diseases. So the question of improving the nutrition of the cattle and the extension of veterinary service is of primary importance in the improvement of dairy cattle in India.

It can be summarised by saying that the milk production in India cannot be improved by any one single method. It can be achieved by a combination of better breeding, feeding, management and disease control of the dairy cattle. Ways and means should be found out by proper investigations, to improve the conditions in these respects. There's a great importance of cattle shows, demonstrations and fairs in order to disseminate, among the cultivators, the improved methods of animal management and production. In India where 90% of the people are illiterate, the initiative must come from the Government and not from the people.

5. <u>Relative Importance of Temperature and Humidity</u>:

Actual experiments have never been carried out in India along these lines. However the general observation is that the wet and misty days rather induces the increased milk yield of the she-buffalo whereas the milk yield of the cow is adversely affected. The atmospheric temperature all over India is well over 100 °F during the summer but the rainfall varies a great deal from province to province. Generally the good breeds of cattle are located in the comparatively dry parts of India such as Sind, the Punjab, Rajputana States, Kathiwar and parts of other provinces where the annual rainfall is usually less then thirty inches but in the flooded areas such as Assam, Bengal, Bihar, Orissa, Madras and Travancore, where the rainfall is seventy inches or higher, the cattle are poor. However the quality of the cattle in these areas depends to a large extent on the abundance and the quality of the feed available, although undoubtedly climate is an important factor.

No doubt the climatic factors, particularly high temperature and humidity, have been the cause of the failure of the European cattle imported in India. The native cattle which have been bred and selected for thousands of years are highly resistant to climatic conditions of India. However, there are breed differences in the degree of resistance and some breeds are more suited to the conditions of a particular area than others.

In the absence of any definite information and considering that the poor nutrition and poor management have been the immediate cause of low production of Indian dairy cattle, it cannot be definitely said how much important are humidity and temperature so far as the dairy production of India is concerned. Colonel Matson (22) who was connected with the dairy husbandry in India for several years, states regarding the effect of temperature, "after a very prolonged study and after being quite sure that the temperature was a formidable difficulty, I came to the conclusion that it is not. I had fully satisfied myself before leaving the country, that the bugbear of temperature was not in any way a difficulty - granted protection from disease carried by biting insects and also granted a more complete food supply than is usual." So it appears that, provided the better dairy strains are selected from amongst the native cattle and provided the food supply is improved and veterinary service extended, the temperature and humidity as are met with in India will not be major obstacles in the way of improvement of dairy production. The influence of temperature on the production and other physiological functions of dairy cattle in general will be dealt with in the subsequent sections.

IV.

HEAT REGULATING MECHANISM (REGULATION OF BODY TEMPERATURE)

Poikilotherms and Homeotherms:

As regards their body temperature animals have been divided into two great classes - Poikilotherms or cold blooded animals and homeotherms or warm blooded animals. In poikilotherms, body temperature fluctuates with that of the environment. When the environmental temperature falls to freezing, their body cells freeze, causing death. Small poikilotherms, therefore descend below the frost-line seasonally, to the lower depths of water, mud or soil, or like some insects, migrate to warmer climates. Poikilotherms which cannot thus migrate to warmer climates often perish. Some very small poikilotherms desiccate and incapsulate for protection.

In homeotherms the body temperature is maintained at a constant level, independant of climatic conditions (Duke[26]; Brody[27]). According to body temperature homeotherms may be divided into several classes. The body temperature ranges from about 36°C (96°F) in elephants to about 43°C (109°F) in small birds. In general the rectal temperature of mammals is about 38°C (100°F) and of birds, 4°C higher, namely 42 - 43°C (107 - 109°F). Typical rectal temperatures - cattle 101°F (38.5°C), horses 100°F (38°C), sheep 103°F (39°C), goats 104°F (40°C), swine 103°F (39°C), cats and dogs 101.5°F (38.6°C), rabbits 103°F (39.5°C), chickens 107.1°F (41.7°C), geese 105°F (40.8°C), doves 41.8°C, rats 37.3°C., elephants 35.9°C.

Rectal temperature classes:-

36 - 38°C (96 - 101°F) -	men, monkeys, mules, asses, horses, rats, mice and elephants.
38 - 40°C (100 - 103°F)	cattle, sheep, goats, dogs, cats, rabbits, pigs.

40 - 41 °C (104 - 106 °F) turkeys, geese, ducks, owls, pelican and vultures.

42 - 43 °C (107 - 109 °F) fowls, pidgeons, quails, partridges, pheasants and sparrows (Brody[27]).

This constant level of body temperature is one which is most favourable to the activity of nerve and muscle and it is maintained in two ways:-

(a) physical regulation and

(b) chemical regulation (Brody; Lusk[28]).

<u>Physical heat regulating mechanism are</u>:

Evaporation of water from skin (sweating) and lungs (respiration); moving of blood to surface (for cooling in sweating species) or to interior; layers of fat for insulation against cold; huddling, looking for shelter, for warm sun, for cool shade, etc.

<u>Chemical temperature regulation</u>:-

Changing metabolic rate by various devices, such as shivering, changing muscle tension, increased adrenaline and thyroxine production and so on.

<u>Heat regulation of homertherms at different environmental temperatures</u>:

The temperature of the living body like that of an inanimate object, tends to come into equilibrum with the environmental temperature by conduction, convection and radiation. (Brody[27] Lusk[28] Armsby[29] Sherman[30]).

Since the homeotherm must maintain its body temperature constant, its heat loss or thermolysis, must equal its heat production, or thermogenesis.

Heat production in the animal body is enormous. It has been stated that, in man and domestic animals, only 20 - 25% of energy produced is converted to mechanical energy and that the remainder must be dissipated as waste heat. (Dill et al[31] Mills[32]). If the body of a man were unable to give off this surplus body heat, a single day would suffice to raise the body temperature to a pasteurising temperature, while in the course of a year, at the same rate a temperature of over 17,000 ^{o}C would be reached (Armsby).

The loss or gain of heat by radiation, conduction and convection is not a unique characteristic of living bodies, although it is only the living body that moves the blood to or from the body surface for the best utilization of these mechanisms. The unique features of homeotherms are:

(1) conservation of body heat - reducing thermolysis - in cold weather by such means as developing fur, feathers, or subcutaneous fat, huddling as well as bundling in some species, finding shelter, increasing heat production by muscular exercise or by increasing specific dynamic action by greater food intake (heat increment of feeding), or by increased production of thyroxine and/or adrenaline, reducing heat conductivity of skin by removing the blood from the surface and reducing evaporation by decreasing respiration rate and by shutting off evaporation from the skin;

(2) dissipation of body heat - increasing thermolysis - in hot weather by reversing the above processes, by reducing the skin covering, moving the blood to the surface for cooling, increasing evaporation rate by producing more surface moisture (sweat), by increasing the respiration rate, and by exposure to moving air (as by fanning).

Thus the pathway for the loss of heat varies with the temperature of the environment. At a low temperature of environment there is little evaporation of water and the heat loss is effected through radiation, conduction or convection. If the environmental temperature is the same as that of the body, the body cannot lose heat by radiation, conduction or convection; it must lose it all by evaporation. If the environmental temperature is higher than that of the body, the body absorbs heat from the environment - radiation, conduction and convection are reversible processes - and the body must dissipate not only the heat produced by it but also that absorbed by it from the environment. This loss can be effected by only one method, evaporation.

Evaporation is a good cooling method because approximately 600 calories or 2400 Btu of heat are dissipated for each quart, or litre of evaporation and it is not unusual for a hard-working normal person to lose by evaporation in a hot dry climate three quarts per hour - over ten times the basal heat production or four times the heat production during hard physical labour.

The importance of evaporation can be best realized from the plight of unfortunate persons lacking sweat glands. They are obliged to keep their clothes moist to enable them to bear normal summer temperature and they are unable to work because of rapidly rising body temperature on slight exertion. Richardson [33] describes a case of congenital absence of sweat glands. The victim was a boy of fourteen. He could not play in the summer-time. He became overheated and had to stop. He would wet his shirt to bring relief. When quiet he was comfortable.

Figure (5) illustrates that as the environmental temperature approaches body temperature heat dissipation is shifted from radiation, conduction and convection to evaporation. There is, however, a striking difference in this respect between the profusely sweating species, man, and other species which are slightly sweating or non-sweating

In man there is a sharp break in the curve for evaporation at temperature 29 ^{o}C or 84 ^{o}F (the critical

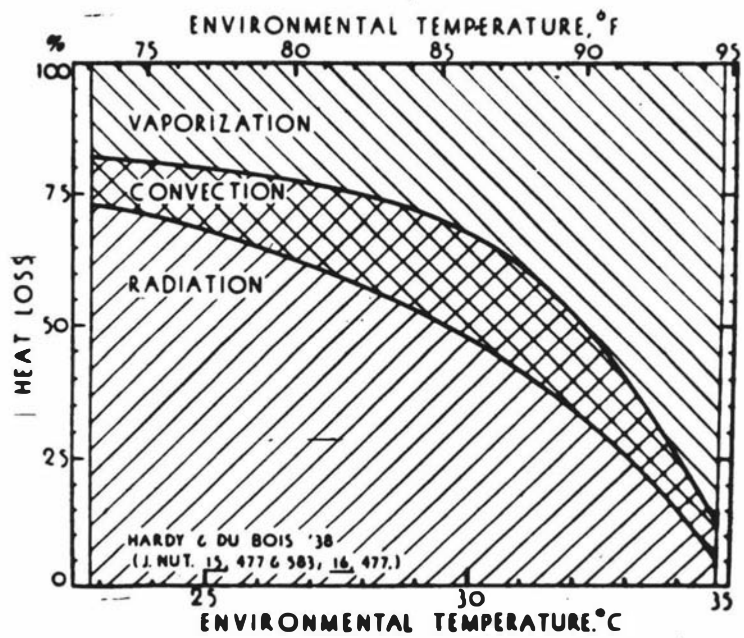


FIG. 5.

Influence of environmental tempe ature on the percentage of heat loss by vaporization, convection and radiation (From Brody[27]).

temperature for sweating in man is between 27 and 32 °C. Up to this temperature evaporation increases irregularly, up to 35% of the total heat dissipation; following this temperature there is a very steep but orderly rise in the evaporation (Brody).

Environmental temperature.		P.C. of total heat dissipation effected by evaporation.
29 °C	(84 °F)	35
35-36 °C	(95-99 °F)	100
40 °C	(104 °F)	200

In other words, at about 100 °F all the thermolysis in man is by evaporation and at 104 °F the body absorbs as much heat from the environment as it produces so that thermolysis by evaporation is twice the thermogenesis. The same holds true for other profusely sweating animals such as the donkey and perhaps for the horse and mule.

The curve of evaporation as a means of heat loss with increasing environmental temperature is quite different in the slightly sweating or non-sweating species, which includes the other farm and laboratory animals. For these species there is no break in the curve at 29 °C or at any other temperature and hence there is no rapid increase in the evaporation with the increasing atmospheric temperature. Their respiration rate goes up enormously but this does not help the animal much above 35 °C (95 °F). Among the farm animals the cattle are non-sweating or slightly sweating; Zebu cattle, however, have more sweat glands than the European cattle (Freeborn et al [34]). Pigs have no sweat glands except on the snout (Robinson et al [35]); sheep have some sweat glands over the body (Dukes [36]); fowls have no sweat glands (Yeates et al [39]). Among the laboratory animals, rabbits (Lee et al [38]), rats and mice (Brody [27]), and dogs (Dill et al[31]) are non-sweating. In these animals the increase in percentage of heat dissipation by evaporation, effected mainly through respiration, rises slowly compared to the profusely sweating species. The plight of non-sweating species in hot weather is evident from the fact that under such conditions man dissipates only one-third of his heat by evaporization from the respiratory passages, two-thirds from the skin (Brody[27]). This is why the respiration rate in man is relatively independent of environmental temperature.

In cattle on the other hand - and this is true of other non-sweating or slightly sweating species, such as sheep, swine, dogs, chickens - the respiration rate rises rapidly with increasing environmental temperature to compensate for the inability to sweat, and to increase the evaporation from the respiratory passages. The manner in which the respiration of cattle is affected by temperature will be dealt with in a separate section.

<u>Relation between chemical and physical heat regulation</u>:-

The relation between chemical and physical heat regulation in homeotherms as influenced by the environmental temperature is illustrated in the diagram (fig. 6). Heat production is plotted against environmental temperature. Temperature segment BB' includes the zone of thermo neutrality, and also that of physical temperature regulation. Thermal neutrality or thermal zero, is the environmental temperature at which heat loss from the body is equal to the minimum heat production. This thermo neutrality temperature is 7-10 ^{o}C (12 to 18 ^{o}F) below the rectal temperature. At thermo neutrality indicated by A in the figure the animal does not employ thermo-regulatory devices, the environmental temperature is perfectly adjusted to keep the body temperature normal without regulation and the

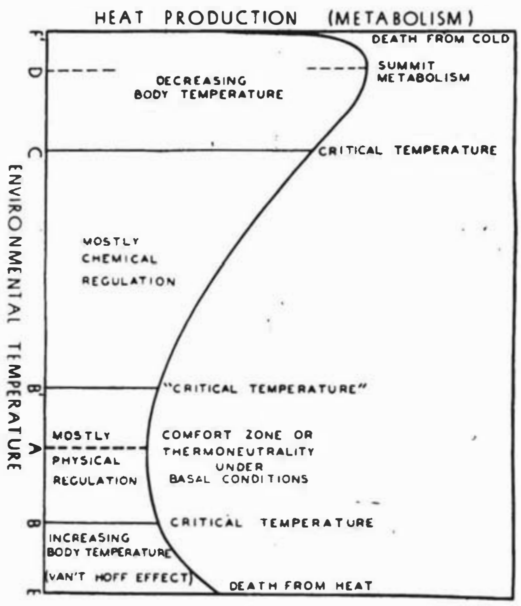


FIG. 6.

Diagram on the influence of environmental temperature on heat production and body temperature. (From Brody[27]).

animal feels neither hot nor cold. Therm-neutrality is presumably the "comfort Zone" for the animal. The comfort zone for man is considered to be between 22 and 30°C (72 - 85°F). Theromogensis (heat production) begins to increase at environmental temperature B' in order to balance the increasing thermolysis. At environmental temperature C the body temperature begins to decline despite the increasing thermogenesis. The temperature-regulating mechanism is no longer able to cope with the cold.

Environmental temperature D represents the position at which heat production is maximum, the summit metabolism. Further decline in environmental temperature breaks down homeothermic mechanism and heat production as well as body temperature declines. At high environmental temperature B the body temperature begins to rise. The position of B varies with (1) sweating mechanism (2) nature of insulation (fur, feathers, fat); (3) size of the animal (4) relative humidity and air movement; (5) body temperature and (6) other factors such as acclimatization etc.

<u>Nervous system in heat regulation</u>:

A few words should be said about the part played by nervous system in the regulation of body temperature. It is now generally known that the sympathetic nervous system controls the caliber of many blood vessels and, therefore, the conducting or insulating properties of the skin (Brody[27] ; Dukes[26]).

The nervous heat-regulating centre is in the hypothalamus, at the head of the spinal cord, just below the cerebrum. In addition to the vasomotor control of the caliber of the blood vessels and, therefore, flow and distribution of blood, the nervous system also controls the arrangement and position of hairs and feathers - as in "ruffling" of feathers or "raising" of hair - so as to decrease or increase thermolysis (heat loss). Tensing of muscles or shivering and other muscular activities associated with heat production are under nervous control, directly or indirectly.

SOLAR RADIATION IN RELATION TO HEAT REGULATION IN CATTLE:

Amount of solar radiation obtained ay any place is influenced by various factors such as

(1) the altitude of the sun,

(2) midday intensities of direct solar radiation,

(3) the length of the days

(4) the number of hours with bright sunshine,

(5) the total amount of sun and sky radiation during various months (Riemerschmid[39]).

The total amount of absorption of solar radiation by the animal body surface comprises the radiation from the sun, the sky and that reflected from the ground on the body surface.

Amount of radiation absorbed by the body surface:

The total amount of radiation absorbed by the body surface of cattle has been found to be strikingly high e.g. more than 20,000 calories, no matter whether the animal is exposed under the conditions of South Africa, Switzerland or Central Europe. Riemerschmid[39] [40] has shown that cattle absorb nearly three times as much heat from radiation as they produce by metabolism during an equal period. This fact points out why the improved European breeds experience great difficulties in regulating their body temperature in the tropics where the atmospheric temperature is already very high. The amount of heat absorbed from solar radiation by the body surface of cattle can be reduced 30 - 40% by providing natural or artificial shade.

Function of coat and skin of cattle in relation to heat regulation:

The amount of absorption of solar radiation or sunlight depends to a large extent on the colour of the coat and also the glossiness and dullness of the coat (Bonsma[41], Riemerschmid et al[42]).

Coat colour:

The animals developed in tropical and sub-tropical regions are light coloured and they reflect more sunlight than the dark coloured animals of the western origin. Bonsma stated that the amount of light reflected from the skins of different animals is directly correlated with colour intensity, that is, the lighter the colour of the animal in the same breed, the greater the amount of light reflected. Riemerschmid (42) stated that colour is the most important factor affecting absorption of solar heat by hiry coats of cattle and the lighter coloured coats contribute towards keeping the animal's skin cool. Bonsma (41) found that the black Aberdeen Angus absorbs the greatest amount of solar radiation. Riemerschmid (42) found the following values of mean effective absorptivity of animals belonging to different breeds.

White Zulu	-	49%
Cream Simmental	-	50%
Red Africaner	-	78%
Africaner x Sussex	-	80%
Dark red Sussex	-	83%
Red Poll	-	80%
Black Aberdeen Angus	-	89%

Bonsma (41) reported that the amount of reflection is the greatest for the light cattle of the Brahman and Jersey breeds. This might be one of the reasons why Jersey cattle has been found to be hardier in the tropics than most of the other dairy breeds of European origin. Another reason is probably that the Jersey was developed in an area with a warm and mild climate. Also the Jersey is a small animal and has large skin surface per unit of weight which helps greatly in maintaining body temperature, particularly when cooling largely depends upon the degree of radiation of body heat. However, animals with dark coats which are adapted to a tropical climatic area, possess other characteristics, besides coat colour (Rhoad)[43]. Rhoad stated that among the black Aberdeen Angus and their crosses with Brahman and Africaner there is little difference in reflection of solar radiation but still they vary greatly in the degrees of heat tolerance. Rhoad considers that the varying degrees of heat tolerance of these black animals must, therefore, be due to physiological differences.

<u>Other coat characters</u>:

The coat of cattle may be glossy or dull. The cattle breeds of temperate origin possess dull coat with long hairs and also an underlayer of wooly hair (Bonsma[41]). This type of coat protects the animal from cold by preventing the radiation of heat from the body and reflecting less amount of sunlight, but is a disadvantage at high temperatures. On the other hand the coat of tropical cattle such as Africaner and Brahman or Zebu have shiny and glossy coats with short hairs, which reflects more solar heat and also help in radiation of heat from the body. These animals have thicker hair and the density per unit area is greater than that of European cattle. In Africaner the average density is 4,700 to 5,000 hairs per square inch compared to 3,000 per square inch in the case of the exotic beef breeds such as Hereford, Shorthorn. Also the average thickness of the hair in the glossy group as represented by Africaner is greater, 50 microns whereas in Shorthorns (dull group) it is 26 microns (Bonsma[44]).

Shorthorns have heavier coats than Africaners. Bonsma[41] found that the average weight of the summer coats of 2-year old Shorthorn heifers was 303 gms. and that of 2-year old Africaner heifers was 29 gms. in summer, their winter coats weighed 505 gms. and 129 gms. respectively.

The author stated that the animals with heavier coats reflect less sunlight than animals with lighter coats.

Character of skin:

Pigmentation of skin is an important factor in reflection of solar radiation by cattle. Harrison (45) stated that the true Brahman, a white or silver haired animal with black points, large drooping ears, often a "mealy mouth," a loose folded skin which has black pigmentation, stands out as a type least discomforted by heat and humidity. Bonsma (41) considers that the yellow pigment in the skin of Jersey cattle is rich in carotene, which is probably a valuable protective pigment against intense solar radiation. This is supported by Rhoad (43) who found that the amount of reflection varies with the intensity of individual pigmentation.

Another factor is the thickness of the skin. Bonsma (44) stated "it appears that the thinner the skin, the greater the amount of heat which penetrates the skin and this results in overheating the body." The following table indicated the thickness of skins in some of the grade cattle in South Africa.

TABLE 1.

Breed (average of 6 animals in each group)	Average skin thickness (cm) Shoulders	Average skin thickness (cm) At 13th rib.
1/2 Sussex	0.347	0.481
3/4 Sussex	0.273	0.382
1/2 Hereford	0.356	0.500
3/4 Hereford	0.309	0.395
1/2 Africaner	0.380	0.510
3/4 Africaner	0.360	0.424
1/2 Shorthorn	0.281	0.380
3/4 Shorthorn	0.261	0.331

The table clearly shows that the skins of high grade Africaners are much thicker than those of the high grade exotic breeds. The author observed that when the atmospheric temperature was 90 °F greater amount of radiant heat penetrated the thinner skins of the Shorthorn cattle and the skin temperature in turn had a direct influence upon the body temperature. In conclusion Bonsma stated "thickness of the skin, therefore to a large extent explains why the Africaner and Hereford breeds are hardier than the Shorthorn and Aberdeen Angus" under the South African conditions.

All this evidence shows that the amount of solar radiation absorbed by the cattle is considerable and is dependent on the colour and character of the coat. The light coloured Zebu cattle with thick pigmented skin and short-haired glossy coat reflect more and absorb less solar heat and are less affected by the tropical sun than the European cattle with unpigmented or poorly pigmented thin skin and dull long-haired coat. However, the higher heat tolerance of the Zebus is, in addition to these characteristics, due to physiological differences.

V

INFLUENCE OF TEMPERATURE ON THE PERFORMANCE OF DAIRY CATTLE:

A. INFLUENCE ON IMPORTANT PHYSIOLOGICAL FUNCTIONS:

1. The Body Temperature of Dairy Cattle:

It has been generally observed that the cattle, on a hot sunny day, feel uncomfortable in the sun and seek shelter in the shade. This is particularly so in the case of temperate breeds of cattle imported in the tropical countries.

Various workers in different countries have studied the effect of environmental temperature, particularly higher temperature upon the body temper ture of cattle of different breeds, specially the cattle of Indian origin (Bos Indicus) and the cattle of European origin (Bos Taurus).

Some observations have also been made on other animals. The influence of atmospheric temperature on the body temperatures of cats (Robinson and Lee [59]), rabbits Lee et al [38]), dogs (Robinson and Lee [60]), pigs (Robinson et al [35]) and sheep (Lee and Robinson [61]) has been studied within the air temperature range of 70° - 110° F under controlled conditions. The normal rectal temperature of these animals was found to be between 100 - 102° F. In these animals the rectal temperature began to rise usually at and above 85° F. The greater the rise in the environmental temperature and the longer the duration of exposure the greater was the reaction of the animal and the more rapid was the rise in the rectal temperature. On the other hand when the temperature was lowered down to 70° F no variation in the rectal temperature of these animals was observed.

Normal body temperature of cattle:

The average normal body temperature of cattle under the ordinary air temperature conditions has been found to be $101^{\circ} \pm 0.5^{\circ}$ F (Galas [62]); (Regan and

Richardson[63]); (Seath et al[64]).

Critical temperature:

Armsby[29] places C.T. of ruminants at approximately 56°F (13°C). Hays[66], studying the influence of atmospheric temperature on B.F. percentage, gives 70°F (21°C) as the temperature, above which the increased metabolism was sufficient to influence mammary secretion. Regan and Meads[67] found the C.T. for producing Holstein cows to be 80°F. However, the critical temperature has a range - the upper critical and the lower critical (cf. heat regulating mechanism). The upper critical temperature of the dairy cows may be taken as the 70 - 80°F., varying with breeds and probably level of production. The lower critical temperature of well fed dairy cows which produce large amounts of extra heat due to feeding must be considerably low (cf. metabolism).

Effect of environmental temperature:

Manresa and Gomez[65] studied the effect of daily variations in the atmospheric temperature on the body temperature of Indian Nellore cattle at the College of Agriculture, Phillipines. Determinations were made at 4-hour intervals during a period of seven consecutive days. He found that the average body temperature of the Nellore cattle during the day (101.66°F) was significantly higher than the average body temperature at night (101.48°F). Also the body temperature between 2 p.m. and 6 p.m. was the highest during the day and this coincided with the hottest hours of the day. However the atmospheric temperatures at these hours have not been mentioned and the manner in which the atmospheric temperature affected the body temperature of these animals cannot be known.

Manresa and Falcon[68] studied the seasonal variations in the body temperature of Nellore cattle. They found the average body temperature of these animals to be significantly higher during the hottest part of the year

(March - July) than the average body temperature during the cooler part of the year (August - February). The correlations between atmospheric and body temperatures ranged from 0.337 to 0.476.

In the Phillipine native cattle (Manresa etal)(69) did not find any significant differences between the average body temperatures during the cool months of the year and those of the warm months. Apparently the native cattle in the Phillipines were not very much affected by the fluctuations of environmental temperature during the year and these animals appear to be more heat tolerant than the Indian Nellore cattle. However no conclusion can be made in this respect because the details about the fluctuations of atmospheric temperatures during the respective periods of observation are wanting.

Manresa and Erce (70), in connection with the problem involved in acclimatization of various breeds of cattle, specially those originated in the temperate countries, studied the fluctuations in the body temperatures of Jersey and Holstein-Friesian cattle in the Phillipines. They found that in both the breeds the afternoon temperatures were significantly higher than the morning temperatures. The authors pointed out that when the afternoon temperatures of the Jersey and Holstein-Friesian cattle were compared, it was found that the Holstein-Friesian constantly showed higher body temperature than the Jersey. The corresponding atmospheric temperatures are not given. The authors, from nine months' observations, found the average body temperatures of Jersey and Holstein-Friesian cattle in the Phillipines to be 102.02 ^{o}F and 102.38 ^{o}F respectively. The body temperatures as given by these authors differ from those given by Smith (71) for the normal dairy cattle in the United States. He gives the range of fluctuation of rectal temperature for dairy cattle, breed not mentioned, as 100.4 to 102.74 °F, with the mean at 101.48 °F. It appears from these figures that the Holstein-Friesian cattle were comparatively more affected by the comparatively higher temperatures in the Phillipines than the Jerseys. This is in agreement with the observations of Freeborn etal [34], who found that the Jersey cows had better control of environmental temperatures than the Friesians. The results are given in the following table.

TABLE 2.

Room Temp.	Body Temp. Holstein.	Body Temp. Jersey.
75 °F.	102.3 °F.	101.5 °F.
80 "	103.3 "	101.5 "
85 "	103.8 "	103.1 "

As the table shows, the Holsteins lost control of their body temperature at 80 °F whereas the Jerseys maintained their normal body temperature until the environmental temperature reached 85 °F. Similar differences in the reactions of the Jerseys and Holsteins to environmental temperature were found by Seath etal [64] in Louisiana. They made observations on thirty six Holstein and forty six Jersey milking cows during the summer of 1944 and forty one Holsteins and twenty seven Jerseys in 1945 in Louisiana where the conditions are such that wide variations occur in both temperature and humidity. Air temperatures during days of observations varied in 1944 from 65 - 93 °F with an average of 85.1 °F. In 1945 the range was from 75 - 91 °F with an average of 85.6 °F. Results of the observations are summarised in the following table.

TABLE 3.

Periods of observation.

	1944			1945		
	Range	Mean	S.D.	Range	Mean	S.D.
Air temp. $^{\circ}$F.	65-93	85.1	6.17	75-91	85.6	4.75
Relat. humidity %.	27-91	56.8	14.06	51-91	73.5	10.0
Body (rectal) temp. $^{\circ}$F.						
Holsteins	100.2 -106.5	103.31	1.27	100.0 -106.0	103.46	1.2
Jerseys	100.3 -105.6	102.60		99.0 -105.9	102.71	

As shown in the table a pronounced differences was found between the Jerseys and Holsteins as regards body temperature. In 1944 the Holsteins' body temperature averaged 103.3 $^{\circ}$F as compared to 102.6 $^{\circ}$F for Jerseys. This took place when air temperatures averaged 85.1 $^{\circ}$F. In 1945 the average for Holsteins was 104.5 $^{\circ}$F or 0.8 $^{\circ}$F higher than that for Jerseys when the average air temperature was 85.6 $^{\circ}$F. Minimum, or normal temperatures were found to be about the same for the two breeds, with higher maximum temperatures registered by Holsteins. The authors also noted that the rate of increase of body temperature as the result of air temperature increase was greater for Holsteins than that for Jerseys. The great difference in size between the Jersey and the Holstein cattle may be a responsible factor for the difference in reactions to high atmospheric temperature between these two breeds (Davidson)[72]. Also the Holstein, being bigger feeders than the Jersey, according to Davidson, normally function on a higher plane of nutrition and hence, are more sensitive to high temperatures and high humidities. They are also not as well equipped for the radiation of heat from their body as are the Jerseys owing to their size (i. e. less body surface per unit weight).

Manresa and Eroe (70) compared the mean body temperature of Indian Nellore cattle taken between 2 and 4 p.m for one complete year with the mean body temperature of the Jersey taken at the same time of the day. They found that the mean body temperature of the Nellore cattle (101.84 ^{o}F) was not significantly different from the mean body temperature of the Jersey in the Phillipines and so the Jerseys compared favourably with the Nellore cattle as regards body temperature, as affected by higher atmospheric temperatures. Nevertheless the raising of Jerseys in the Phillipines has not been generally successful. Hence the authors concluded that environmental temperature is not the only factor involved in the difficulties of raising cattle of temperate climate origin in the Phillipines.

In his studies at Jeanerette during the summer of 1937, Rhoad (73) used Aberdeen Angus cows as representatives of Bos Taurus species and Guzerat cows as representatives of Bos Indicus or Brahman species. The crossbred types were F_1 and F_2 back crosses of Aberdeen Angus x Guzerat matings. His observations give further evidence showing that high atmospheric temperature influenced in unlike manner the body temperatures of typical Bos Taurus and Bos Indicus cattle. He found that the body temperature of Bos Taurus animals, represented by Aberdeen Angus, were influenced to a greater degree by high atmospheric temperatures than that of Bos Indicus animals represented by the Guzerat breed. He further observed that, when exposed to direct solar radiation under summer climatic conditions the body temperatures of all these cattle responded upwards producing, when exposed for a considerable length of time, a febrile condition in the Bos Taurus animals.

Rhoad [74] made further studies on the fluctuations of body temperature in order to determine the part played by genetic differences in adaptability of cattle. Rectal temperature readings were made on each of the genetic types as an index to their efficience in disposing of excess body heat. Mean rectal temperatures at various shade temperatures, with experimental animals held in the shade, were as follows:-

TABLE 4.

Temp. - °F.

Shade temp.	Purebred Angus.	¾Angus - ¼Brahman.	½Angus - ½Brahman.	Purebred Brahman.
86 - 95	102.8	101.9	100.9	101.0
76 - 85	101.7	101.4	101.0	101.0
66 - 75	100.4	100.7	100.6	100.7
56 - 65	99.9	100.8	100.6	100.1
46 - 55	99.7	101.1	100.5	99.2

The table shows that as atmospheric temperatures increase above 50 °F there is a general increase in rectal temperatures, within each genetic type. This is most evident with the purebred Aberdeen Angus. The pure-bred Brahmans were least affected and the pure-bred Aberdeen Angus were most affected by the high atmospherci temperatures and the reaction of the grade animals increased with the increase in the percentage of Angus blood in them.

Imparting heat to the animal body through exposure to direct sun rays caused an added burden on the process of heat disposal which is reflected in the increased rectal temperatures of the experimental animals as shown in the following table:-

TABLE 5.

Mean rectal temperatures with cows in the shade and in the sun (°F).

Shade temp.	Cows held in	Purebred Ab. Angus	¾Angus - ¼Brahman	½Angus - ½Brahman	Purebred Brahman
86 - 95	sun	104.0	103.4	101.8	101.3
	shade	102.8	101.9	100.9	101.0
76 - 85	sun	102.4	101.9	101.1	101.1
	shade	101.7	101.0	101.0	101.0

The values indicate that at 80°F in the shade the pure-bred Aberdeen Angus and the three-quarter Angus were significantly influenced, whilst the half-bred and pure-bred Brahman were not significantly affected by exposure to direct sunrays. At 90°F., however, the body temperature of each genetic type was significantly influenced by direct solar radiation although the differences with the half-bred and pure-bred Brahman were only slight. This is further emphasised in the figure (7) which shows the course of body temperatures for each genetic type in one of the severest tests of the experiment carried out by the author.

In conclusion the author stated that "the pure-bred and ¾-bred Aberdeen Angus are not physiologically adapted to the high temperatures and intense solar radiations of tropical climates."

In his subsequent experiments Rhoad[75] [76] attempted to measure heat tolerance of beef cattle of Indian and European origin. The heat tolerance was obtaine by subtracting from 100 the number of tenths of a °F. by which normal body temperature (101°F) was exceeded when the animals were kept in the sun with shade temperature of about 90°F. The values of the coefficient of heat tolerance obtained on 198 animals over 3-years' period are as follows:-

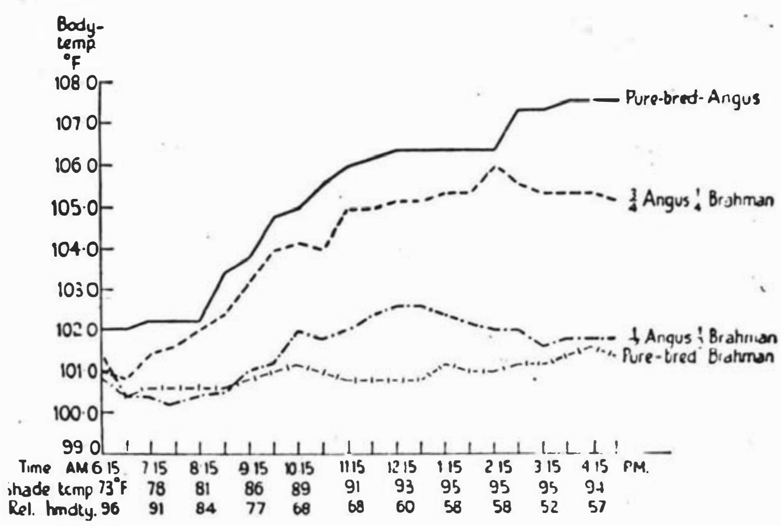


FIG. 7.

Course of body temperature of experimental animals exposed to direct sun rays on a clear calm summer day. (From Rhoad, A. O. (74)).

TABLE 6.

Animals	Coeff. of heat tolerance.
Pure-bred Brahman	89
$\frac{1}{2}$ Brahman - $\frac{1}{2}$ Angus	84
$\frac{5}{8}$ " - $\frac{3}{8}$ "	84
Pure-bred Santa Gertrudis	82
$\frac{1}{2}$ Africaner - $\frac{1}{2}$ Angus	80
Pure-bred Jersey	79
$\frac{1}{4}$ Brahman - $\frac{3}{4}$ Angus	77
Grade Hereford	73
$\frac{1}{4}$ Africaner - $\frac{3}{4}$ Angus	72
Pure-bred Aberdeen Angus	59

Similar observations were made by Bonsma (44) in his experiments at Messina, South Africa, with bulls of Hereford, Aberdeen Angus, Shorthorn and Africander cattle. The body temperature, atmospheric temperatures in the shade as well as in the sun were recorded. The following table indicates the various fluctuations of atmospheric and body temperatures of the animals at 1 hour intervals between 8 a.m. and 5 p.m.

TABLE 7.

Time	Temp. (°F)		Body temp. of bulls (°F)				
	Sun	Shade	Hereford No. 3	Ab. Angus No. 3606	Shorthorn No. 6	Africander No. 62	Shorthorn x Africander F. 1
8. a.m.	81	78	102.2	102.9	102.8	102.1	102.1
9 "	82	80	102.3	102.9	103.3	102.2	102.1
10 "	84	83	102.6	103.2	104.4	102.3	102.1
11 "	84	83	102.6	103.6	105.6	102.3	102.1
12 "	90	90	102.8	104.2	107.2	102.3	102.0
1 p.m.	94	91	103.4	105.2	106.0	102.2	102.0
2 "	97	92	103.5	106.4	106.0	101.5	102.2
3 "	101	94	103.7	106.2	105.8	102.0	102.2
4 "	100	93	103.4	106.2	106.3	101.9	102.3
5 "	95	93	102.7	105.8	106.6	102.0	102.1

From the table it clearly appears that as soon as the atmospheric temperature in the shade rose above 80 ^{o}F it was accompanied by a rise in the body temperature of animals belonging to exotic beef breeds but the body temperature of the Africander bull remained constant and in this respect the Africaner can be compared with the Guzerat or Nellore cattle of Indian origin. The figure (8) clearly indicates the trend in the rise of body temperature of these different breeds.

The author stated that even during winter the regulation of body temperature, in particular the expulsion of surplus heat, was an important problem to cattle belonging to the exotic beef breeds. "Although the solar radiation intensity recorded in gram calories per square cm. per minute on a self-regulating galvanometer has greatly diminished by 3 to 4 p.m., there is still a constant rise in body temperatures of bulls belonging to the exotic beef breeds." This clearly indicates that during the earlier part of the day, when the solar energy was high, these animals accumulated an excessive amount of surplus heat which could not be expelled immediately. He further observed that the amount of heat accumulated in the body was so great that the animal body was in a state of fever even long after the atmospheric temperature has declined to below the critical temperature which was apparently considered to be 80 ^{o}F for these animals. In this respect Manresa et al [69] also reported that Holstein-Friesian cattle and also Herefords in the Philippines were frequently seen panting most frightfully in the shade while Indian Nellore cattle were comfortably grazing in the direct rays of the sun.

That the exposure to the sun further increases the reactions of the cattle has also been observed by Galas [62]

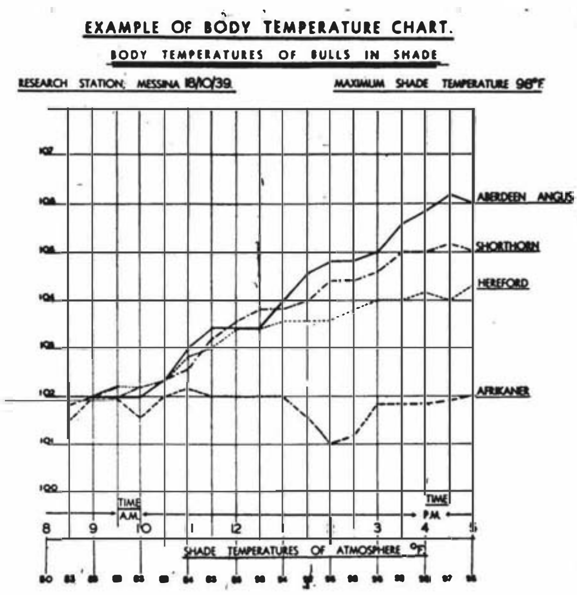


FIG. 8.

Body temperature at varying atmospheric temperatures.
(From Bonsma, J.C. et al [44]).

in Jersey cattle in the gulf coast region of Louisiana. He reported that keeping cows in the sun at higher temperatures (up to 95 °F) caused an average rise of 0.7 °F in body temperature as compared with the body temperature of the same cows kept in the shade at the same air temperature. The relationship between atmospheric temperature and the body temperature of the cattle was statistically analysed by Galas (62). He took a total of 3,298 individual readings of body temperatures of Jersey cattle at various air temperatures over a 16-month period. The author found a wide range of body temperature of the individual cows even at lower temperatures, the range being from 98 to 103 °F. at air temperatures below 70 °F. and this showed no relationship to air temperature ($r = -0.08$); but at air temperature above 70 °F the average body temperature increase consistently with the increase in air temperature and the author found a definite relationship between body temperature and air temperature ($r = +0.59$).

Seath et al (64) (78) also, found a definitely high and positive correlation between body temperatures of Holstains and Jerseys and air temperatures within the range of 65° - 93 °F during two seasons (1944 and 1945). They separated the effect of humidity on body temperature. The correlation between air temperature and body temperature for 1944 was 0.674, and for 1945, 0.534. So far practically no observations have been made on the effect of very low environmental temperatures upon the body temperature of dairy cows and we have little idea about how the body temperature reacts to the temperatures as low as freezing point or even lower than that nor could we know the lower critical temperature of the dairy animals if there's any. However, Harlass (77) subjected Black Pied Lowland cows to temperatures as low as 6 °C (42.8 °F). In a winter experiment (from 1st December 1939 to 1st February 1940) he kept six animals in heated byres at six different temperatures 24°C (75.2°F), 20°C (68°F), 16°C (60.8°F), 15°C (59°F), 10°C (50°F) and 6°C (42.8°F). He found that the body temperatures rose to the "upper limit of the normal range" at high byre temperatures, but remained constant between 16°C (60.8°F) and 6°C (42.8°F). It has not been stated what the author considered to be the normal range of body temperature and consequently what the "upper limit of the norma range" was, could not be known. Also because the details of the experiment were not obtainable, no idea could be made about the procedure adopted and no definite conclusion can be arrived at as to the effect of low atmospheric temperature on the body temperature but most probably the body temperature is very much less or not appreciably ffected by the low as compared to the high atmospheric temperatures.

<u>Relative importance of humidity</u>:

In rabbits (Lee et al)[38], cats (Robinson and Lee)[59] dogs (Robinson and Lee)[60], pigs (Robinson et al)[35] and sheep (Lee and Robinson)[61] it has been definitely shown that at higher atmospheric temperatures (above 85°F) the reaction of these animals is further increased by high relative humidity and also the higher the air temperature the greater is the effect of humidity on body temperature, Seath et al[64] studied the effect of relative humidity on the body temperature of Jersey and Holstein cattle during two years (1944 and 1945) within the range of 27 - 91%. Using their fairly extensive data they found the correlation coefficients to be 0.458 for 1944 and -0.559 for 1945. No explanation has been given why the correlation between humidity and body temperature took a reversal form in two years. They also obtained the following multiple regression equations having x to represent air temperature and y to

represent humidity. For 1944, estimated body temperature = 0.1364 x + 0.0099y - 9.08.
For 1945, estimated body temperature = 0.1988x +0.0129y - 14.80
Multiple regression equations indicate that one degree increase in air temperature was responsible for from 13 to 15 times increase in body temperature as was an increase of one percent in humidity.

The authors concluded that "changes in air temperature to be the major cause of increases in body temperature." However their conclusion does not necessarily mean that relative humidity has no influence on body temperature at all. It might be that humidity has not as great an influence as atmospheric temperature.

2. Effect of temperature on respiration and pulse rates:

Respiration rate and probably pulse rate too are a measure of an animal's ability to eliminate surplus body heat and as such respiration and pulse rates, and particularly respiration rate like body temperature, may be related to the ease or difficulty with which an animal can dispose of extra heat produced in the body due to higher environmental temperature and/or the metabolic function.

How respiration eliminates heat?

Expired air is heated practically to the temperature of the body and is practically saturated with water vapour. Since the temperature of the inspired air is usually distinctly below that of the body and the water vapour content usually below saturation, breathing is the cause of heat loss from the body by reason of warming the inspired air and evaporating water from the lungs (Dukes)[79].

In non-sweating or slightly sweating animals like cattle respiration i.e. evaporation of water through lungs is the principal means of getting rid of surplus heat. Sweating mechanism, however, is more developed in the Zebus (Bos Indicus) (cf. heat regulating mechanism). Kelly[2] stated "Zebus have retained and European cattle have practically lost their ability to perspire, i.e. sweat." French[80] reports that as soon as the air temperature rises above the region of thermal neutrality, from one-and-a-half times to twice the amount of water is vaporized through the skin of Zebus as compared with that of European cattle. It seems likely, therefore, that, as in the case of body temperature, the Zebus will be less affected by high atmospheric temperatures than the Bos Taurus animals so far as the respiration and pulse rates, particularly respiration rate, are concerned.

Animals other than cattle:

In rabbits (Lee et al)[38], cats (Robinson and Lee)[59], dogs (Robinson and Lee)[60], and pigs (Robinson et al)[25] it has been found under controlled conditions (temperature range 70°F - 110°F) that the respiration rate (normal 50 - 60/minute) began to rise slowly at 75°F above which it rose with greater and greater effect as the air temperature increased to 110°F.

In sheep (Lee and Robinson)(61), however, the respiration rate did not markedly increase until above 90°F.

The rise in pulse rates of these animals was very much less compared to the rise in respiration rate. However it showed a moderate but definite response to high environmental temperature, increasing above 90°F or so.

One thing is apparent from these observations that the respiration rate begins to rise at a lower atmospheric temperature than is necessary to affect the body temperature. It is expected considering the fact that the animal attempts to maintain body temperature by increasing respiration rate and that the body temperature would not rise until the increased rate of respiration fails to cope with the increased rate of heat production at higher atmospheric temperatures.

<u>Cattle</u>:

Apart from environmental temperature, other factors such as production of cows and plane of nutrition, shearing etc. may influence the respiration and/or pulse rates to some extent.

Fuller(81) gives a brief summary of 1692 observations of pulse and respiration counts in four breeds of cows - Holstein, Jerseys, Ayrshire and Guernseys - in relation to milk production and summer and winter temperatures, which shows that both rates are capable of great change. Fuller himself says that, in the dairy herd, there was no correlation between either respiration and pulse rates and age, milk yield or temperature. His data might be interpreted differently. From the data presented, it appears that there might be a bred difference in both pulse and respiration rates, Holsteins and Ayrshires having higher maximum and average rates than Guernseys and Jerseys, which might be correlated with higher average milk yield. It further appears that there might be differences in respiration and pulse rates within the breed according to level of production. This is, to some extent, supported by Ritzman and Benedict (82) who found that the same cow has higher pulse rate when milking than when dry.

They also found the pulse rates of steers to vary in relation to the plane of nutrition; the average for submaintenance periods being 33, for maintenance 44, and during fattening 78 beats per minute. These differences are highly significant. Respiration rates are not given. It would be interesting to know if respiration rates also varied with the plane of nutrition.

Mitchell and Hamilton (83) found in steers that shearing may bring about a small difference in pulse rate in favour of the shorn steer.

Normal respiration and pulse rates:

In beef cattle Bonsma stated that normal respiration rate should be 20 per minute. Galas (62) and Seath et al (64)(78) consider that normal respiration of dairy cattle is 22 per minute. Dukes (84) gives normal pulse rate per minute of ox as 40 - 60 and of dairy cow as 60 - 70.

Effect of high atmospheric temperatures:

Seath and Miller (85) in Louisiana observed the day time changes in body temperature, respiration and pulse rates. Observations were made on six milking cows, three Jerseys and three Holsteins. Pulse counts were made from coccygeal arteries of the tail, and respiration counts from flank movements and these counts were taken during five periods of the day over three days in September. The results are given in the following table:

TABLE 8.

Time of day	Air temp.	Relative humidity	Body temp.	Respiration	Pulse rate
5.45 a.m.	73.0 °F	89.3%	101.7 °F	63 per min.	66 per min.
9.20 "	80.6 "	81.3"	102.4 "	64 " "	67 " "
10.20 "	83.1 "	74.3"	102.6 "	71	66 " "
2. 0 p.m.	86.7 "	73.0"	103.3 "	78 " "	68 " "
3. 0 "	86.0 "	65.3"	103.5 "	79 " "	67 " "

This observation gives indication how the three variables body temperature, respiration rate and pulse rate reacted simultaneously to the changes in atmospheric temperature during the day time. The table shows that, on averaging for the day, 1.8 °F increase in the body temperature was accompanied with an increase of 16 respirations per minute and 1 pulse beat per minute. Between 73 and 80 °F of air temperature respiration rate was not much affected but above 80 °F the rise in the respiration rate was rapid and continuous. At these temperatures the cows were apparently unable to eliminate heat fast enough to prevent further changes in their body temperature and respiration rate and as a result both increased. Relative humidity decreased from 81.3 to 74.3 p.c. and even if this should help in heat elimination the help was not great. The change in pulse rate was not significant.

Galas (62) studied the respiration rate of milking Jersey cows as affected by air temperatures under the conditions of Southern Louisiana. The cows were in normal health and uniformly fed throughout the period of observation (16 months). A total of 3,298 readings of respiration rate were made at various temperatures. The huge amount of data produced by him shows that the average respiration rate began to increase at a lower air temperature (51 °F) than did the body temperature

(70 $^\circ$F). The rate continued to increase slowly as the air temperature rose to 67 $^\circ$F and then began to increase more rapidly. His data further shows that there was a great variability in the respiration rate amonng the individuals at ordinary air temperatures but this variability increased, as the air temperatures rose, with a sharp increase at 69 $^\circ$F and above. The respirations per minute for individual cows ranged from 8 to 78 at air temperatures below 69 $^\circ$F and from 16 to 127 at air temperatures above 69 $^\circ$F. He found that the average respiration rate ranged from 20 per minute at an average air temperature of 50 $^\circ$F to 90 per minute at an average air temperature of 95 $^\circ$F with a correlation coefficient of 0.77. This shows a very high correlation between air temperature and respiration rate.

Similar observations were made by Regan and Richardson (63) in their studies of respiration and pulse rates with six pairs of high producing dairy animals of Holstein, Jersey and Guernsey breeds under controlled conditions at California Experimental Station. The animals were kept in a large psychometric room in which the air temperature was increased from 40 to 100 $^\circ$F. Except for changes in environmental temperature, uniform conditions were established. The cows were held at each temperature for a period of 5 to 10 days. Data for the first 2 days of the period was, however, not included. The results are given in the following table:

TABLE 9.

Room temp. $^\circ$F.	Body temp. $^\circ$F.	Respirations per minute.	Pulse rate per minute.
40	101.1	12	-
50	101.0	17	72
60	101.0	28	68
70	101.3	42	63
80	101.8	56	61
85	102.2	70	59
90	102.7	88	60
95	103.7	106	57
100	105.1	124	-

That the respiration and pulse reates do not necessarily increase together is supported by Regan and Richardson's data. The table shows that the respiration and pulse rates were actually inversely affected by the high atmospheric temperatures. As the room temperature increased there was a rise in the respiration rate and a fall in the pulse rate but the respiration rate was comparatively much more affected than the pulse rate. The table also shows that the respiration rate began to increase at a lower atmospheric temperature as compared with the body temperature. The increase in respiration rate, although within the normal range, was first noticed at 50° F whereas the body temperature did not rise until 70° F. This is in full agreement with Galas's observations. Regan and Richardson's data present an interesting study. According to Vant Hoff's law the speed of chemical reaction is approximately doubled with each increase of 10° C (18° F). It has been shown by others (Brody)[27] that this law applies to the breathing of poikilothermous animals. Regan et al's data obtained with cows fit this law quite well. It becomes also clear that this automatic control of body temperature by breathing probably comprises the cow's principal method of heat regulation. The effect on the pulse rate appears to be another physiological difference between man and the cow in their response to heat. While the pulse beat of man speeds up in an overheated condition, that of the cow as shown by Regan and Richardson tended to slow down. The authors consider that these facts are in thorough accord with the method of heat dissipation used by each. They stated "Man's firstline of defence against a pyrexial condition is to increase the flow of blood through the capillaries of the skin, hence, an acceleration of the heart rate facilitates the elimination of heat from the body. Since the cow does not sweat, her dry skin in a hot environment may actually acquire a temperature above that of the body, in which case increasing the rate of circulation would tend to place an added burden upon the heat dissipation mechanism while a slowing of the heart rate would be actually beneficial."

However this is not in complete agreement with the observations made by others in other non-sweating smaller animals such as rabbits, cats, dogs and pigs. In these animals the pulse rate slightly tended to rise at environmental temperature above 90 °F or so and this apparently seems to be more likely considering the fact that blood circulation appears to increase at high environmental temperatures.

Freeborn et al (34) found in rabbits that blood vessels of the skin were dilated and more blood was passed into them as the room temperature increased. They measured the diameter of a given capillary in a rabbit's ear with a binocular microscope and an eyepiece micrometer at given temperatures and found the following results:-

Room temperature	50 °F	70 °F	80 °F	90 °F
Dilation	.84 mm.	1.05 mm.	1.05 mm.	1.89 mm.

This dilation of blood vessels of skin and the increased blood flow in them facilitates heat radiation as well as evaporation from the skin. This evaporation of course is not sweating and occurs in all animals (sweating or non-sweating) including man. Whitehouse et al (86) calls this "osmotic water" which passes freely through the skin by osmosis or diffusion in increasing amounts as the atmospheric temperature is increased. In sweating animals however, the passage of this so-called osmotic water stops, when the sweating commences and the skin surface becomes saturated with

with sweat. This kind of water loss from the body has been called insensible water loss by Dukes (36).

So it appears that in non-sweating animals like rabbits, as well as cows, more blood will be pumped into the peripheral blood vessels at higher temperatures in order to effect a part of heat loss through radiation, conduction and osmatic evaporation. Under these conditions pulse rate is likely to increase in order to speed up blood flow and the increase is likely to continue until the air temperature approaches body temperature at which no more heat will be radiated from the body. At a temperature higher than body temperature the body will absorb heat and, therefore, it will be to the advantage of the animal to slow down the pulse rate and decrease the blood flow in the blood vessels of the skin. These conditions are however likely to be modified by the presence or absence of hairy coat affecting heat radiation - conduction process and osmatic evaporation; and also by the presence of sweat glands in which case increased blood flow will be maintained at all higher temperatures to facilitate sweating. This explanation seems to agree with the results obtained by the workers with rabbits, cats, dogs and pigs and also with Seath et al's (64) observations with Holstein and Jersey cows within the air temperature range of 65 - 93 ^{o}F. These latter workers found that both simple and partial correlations between air temperature and pulse rate were positive and averaged slightly less than 0.2, Seath and Miller (85) also noted slight increase in pulse rate with the increased atmospheric temperature.

Regan and Richardson's (63) explanation of decreased pulse rate at high environmental temperature is reasonable at very high temperature but this is not convincing enough for the decrease in the pulse rate at a temperature as low as

60 °F and when the animals were not possibly exposed to direct solar radiation. However the change in the pulse rate of the cows apparently is very small as compared with that in the respiration rate.

As in body temperature a great difference has been reported by Rhoad[87] and others between the Bos Taurus and Bos Indicus cattle in their respiratory reactions to higher environmental temperatures. Rhoad studied the respiration rates of pure-bred Holstein, Holstein-Zebu crosses ($\frac{3}{4}$ to $\frac{15}{16}$ Holsteins) and Zebus under tropical conditions in Minas, Brazil, and found a very large breed difference between the pure-bred Holsteins and Holstein-Zebu crosses on the one hand and Zebus on the other, as shown in the following table.

TABLE 10.

Average respiration rate at varying degrees of external temperature.

Animal	Aver. weight Kg.	Average respiration rate per min.				
		11°C	19°C	23°C	29°C	36°C
5 pure-bred Holsteins	565	28.0	30.2	44.4	92.4	107.0
8 Holst.-Zebu crosses	436	20.0	22.4	29.8	74.0	89.3
2 Zebus	432	23.0	23.0	27.0	34.5	46.0

The trend in the change of the respiration rate of these animals is clearly shown in Figure (9). The figure and the table point out that the cattle of European and Indian origin responded differently to high thermal environments and that their crossbred types responded in an intermediate manner. The respiration of the pure-bred and high grade Holstein began to rise at 19 °C (66.2 °F) but that of Zebus remained constant at this temperature. Between 23 °C (73.4 °F) and 29 °C (84.2 °F) the respiration rate of

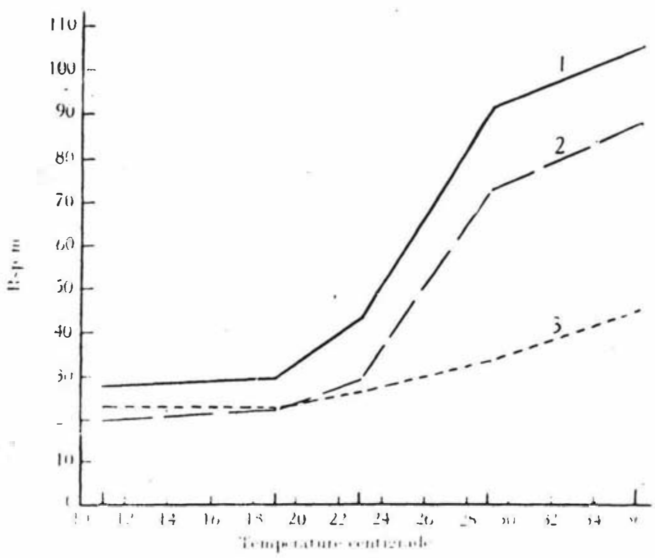


FIG. 9.

Respiration per minute at varying degree of external temperature.

1. Purebred Holstein.
2. Cross-bred Holstein-Zebu.
3. Zebu.

(from Rhoad, A. O.[87]).

pure-bred and high grade cross-bred European cattle was considerably increased, while that of Indian cattle was only slightly increased. Between 29 and 36 °C (96.8 °F) respiration rate was further increased. "At 36 °C the European cattle," Rhoad states, "have apparently reached their maximum efforts of physical regulation through the lungs." This however is not indicated in the respiration curve for Zebu cattle. The respiration curve of the cross-breds with high percentage of Holstein blood, although lower than that of the pure-bred group, is of the same type as of the latter.

During the period of observation relative humidity varied from 67 to 81 p.c. the maximum corresponding with the maximum temperatures. Although Rhoad did not analyse the part played by humidity he stated that high external temperature and humidity influenced "the respiration rates of European and Indian cattle in unlike ways, indicating a species difference in the manner of response to tropical temperatures." He suggested that "the loss of energy in dairy cattle as the result of higher atmospheric temperatures is in a large way responsible for the low production records of European dairy cattle in the tropics." He attributed this "loss of energy" to the convulsive respiratory movements which were often so strong that the whole body was forced into a rhythm with the flank movements. He further stated that the primary cause of the break down of these animals at higher temperatures was the almost complete failure of heat disposal by radiation and the shift of the burden on to the water evaporation through the lungs. These observations were supported by Rhoad's (73) further studies made at Jeanerette using Aberdeen Angus as representative of Bos Taurus and Guzerat cows as representative of Bos Indicus. The cross-bred animals used were F_1 and F_2 back-crosses of Aberdeen Angus and Guzerat matings. The observations were

were made during the summer. He found that the respiration rates of these animals rose and fell concurrently with the rise and fall of atmospheric temperature during the course of the summer day. He further observed the additional adverse effect of the direct sun on the respiration rate. The figure (10) shows that when exposed to the direct sun under summer conditions the respiration rate of all these cattle responded further upwards but more so with Bos Taurus animals than with the Bos Indicus. It is also evident from the figure that the F_1 crosses of Bos Taurus x Bos Indicus showed greater efficiency in heat disposal and hence smaller rise in the respiration rates than the back cross animals to the Bos Taurus. That the higher percentage of Zebu blood in a cross bred animal increases the efficiency in disposal of sur plus heat at higher atmospheric temperatures is further supported by his [74] observation in connection with his studies on the genetic differences in the adaptability of cattle to tropical and sub-tropical climates.

Results were as follows:-

TABLE 11.

Mean rate of respiration at various shade temperatures with the experimental animals held in the shade (respiration per minute).

Shade Temp. °F.	Purebred Angus.	3/4 Angus-1/4 Brahman.	1/2 Angus - 1/2 Brahman.	Purebred Brahman.
86 - 95	88.9	88.0	44.8	32.7
76 - 85	67.6	44.4	31.8	25.5
66 - 75	50.3	28.4	26.7	22.3
56 - 65	34.0	23.5	20.8	19.1
46 - 55	20.2	15.3	11.6	12.7

The table clearly shows the influence of Zebu blood in an animal on its response in respiration rate to higher atmospheric temperatures. In this respect the animal with 50% Zebu blood is more similar to purebred Zebus

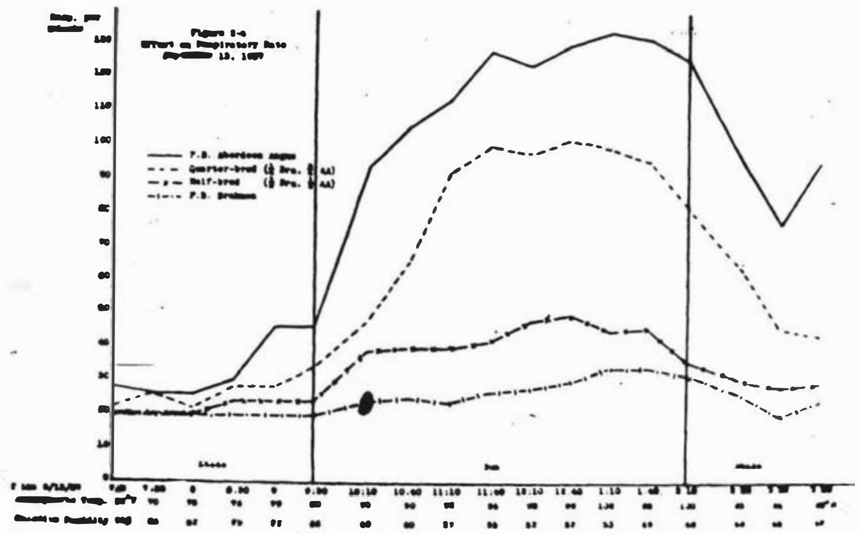


FIG. 10.

Respiratory rate at varying atmospheric temperatures (sun and shade).
(From Rhoad, A. O. (73)).

and that with 75% Angus blood is more similar to purebred Angus. Similarly Bonsma (44) in South Africa found great genetic differences between Africaner cattle belonging to exotic beef breeds such as Hereford, Aberdeen Angus and Shorthorn. Atmospheric temperatures were taken in the sun and shade and the respiration counts of the animals were taken in the sun. The data presented by him shows that, as the atmospheric temperature rose above 80 °F it was accompanied by a considerable increase in the respiration rate of animals belonging to exotic breeds. There appears to be some breed difference. The Aberdeen Angus and the Shorthorn animals seemed to react similarly and more strongly than the Hereford animal. The Africaner animal like the Zebus (both belonging to Bos Indicus) and the Shorthorn x Africaner F_1 animal were very much less affected and their respiration rates did not seem to increase significantly within the sun temperature range of 81 - 101 °F. In contrast to Rhoad's observation, the Shorthorn x Africaner F_1 animal appeared to be more efficient than the purebred Africaner. However, considering the very small number of animals used by Bonsma, Rhoad's observation is more conclusive. In conclusion Bonsma stated "In the case of exotic breeds, the respiratory centre loses its normal function of controlling the rhythmical movement of respiration when the temperature rises above 80 °F, their breathing consequently being rapid, irregular and shallow."

Bonsma (88) found similar genetic differences among calves belonging to Africaner breed and exotic beef breeds, in their respiratory reactions to high environmental temperatures.

Seath et al (64) studied the relationship between the air temperature within the range of 65 to 93 °F and respiration rates of Jersey and Holstein cattle. They made observations on 36 Holstein and 16 Jersey cows over 2 years. The partial correlations between air temperature and respiration rate (humidity held constant) were found to be 0.748 and 0.353 for the respective years. The first year's correlation coefficient is similar to that found by Galas (62) (r=0.77

Effect of humidity on respiration and pulse rate:

Workers with rabbits, cats, pigs and dogs found that humidity had no effect on the respiration rate of these animals at lower environmental temperatures but at higher temperatures (95 - 110 °F) humidity (25 - 95%) had a definite effect. They found that high humidity further increased the respiration rate ofthese animals at high temperatures and that the effect of humidity was greater and greater with the increase in temperature and humidity and that low humidity had a sparing action on the respiration rate at these temperatures.

In these animals humidity had no definite effect on pulse rate. However at comparatively lower temperatures (70 - 95 °F) the rate tended to fall slightly and at higher temperatures (100 - 110 °F) had a slight tendency to increase with higher humidities. In dairy cows (Jersey and Holstein) Seath et al (64) studied the effect of humidity on the respiration and pulse rate. On the partial correlation basis they found a negative correlation between relative humidity (27 - 91%) and respiration rate, that is, increase in humidity slightly lowered the respiration rate. This appears to be contrary to the observations made with smaller animals (mentioned above) under controlled conditions, and because Seath et al's results were obtained under uncontrolled (ordinary) conditions of temperature and humidity no conclusion can be drawn from their results. However, the effect of humidity was not so important as compared with the environmental temperature. On the basis of multiple regression equation these authors have shown that one degree change in air temperature was responsible for from 41 to 43 times as much change in respiration rate as one percent change in humidity. The authors concluded that "Changes in air temperature appeared to be the major cause of increase in the respiration rate of milking cows."

Their analysis of relationship between humidity and pulse rete on the basis of partial correlation (with air temperature constant) gave a value of -0.05 for the first year and 0.07 for next year, thus leaving a question to its real relationship. In conclusion the authors stated "pulse rates were less affected by either air temperature or relative humidity" in comparison with their effect on the respiration rate of milking cows.

It can be concluded that high atmospheric temperature greatly affect the body temperature and respiration rate of cattle. Pulse rate is not appreciably affected. The upper critical temperature of dairy cattle may be considered to lie between 70 - 80 ^{o}F depending on the breed and individuality. As the atmospheric temperature rises above this upper critical limit elimination of body heat becomes a problem for the animal. As a consequence the respiration rate and body temperature increase and at a greater rate with the increase in air temperature. However the Bos Indicus cattle are genetically different from the Bos Taurus cattle in this respect. At higher temperatures and particularly in the sun, the body temperature and respiration of the Taurus cattle increase considerably whereas the Zebus are not significantly affected. The high heat tolerance of the Zebus is due to their better heat-regulating mechanism (presence of sweat glands, coat character and other hereditary factors). Under the tropical temperature conditions the degree of heat resistance of an animal is proportional to the percentage of Zebu blood in the animal. Higher humidity may aggravate the reactions of the cattle at higher temperatures, by adding an extra burden to the problem of heat disposal. However the effect of humidity is comparatively much less than that of the environmental temperature.

3. **Blood of Dairy Cattle:**

Purebred dairy stock of temperate origin fail to adapt to the tropical and subtropical climates. Some workers undertook studies on the haematology of these animals in an attempt to determine whether the changes in the blood picture of these animals, when imported into the tropical and subtropical countries, could be taken as a physical basis for evaluating the degree of their adaptability to the tropical and subtropical climates.

Manresa and Ryes (89) studied the haemoglobin content of Phillipine native cattle, and Indian Nellores, Holsteins and herefords imported in the Phillipines. The haemoglobin content per 100 c.c. of blood of these animals was found to be as follows:-

Indian Nellore - 9.87

Phillipine Native - 9.46

Holstein-Friesian - 8.28

Hereford - 6.76

In later studies Manresa et al (90) found still lower haemoglobin index (6.86) for the Holstein-Friesians in the Phillipines. These figures for the Friesians in the Phillipines are significantly lower than those reported for the same breed in U.S.A. McKay (91), Neal and Becker (92) and Brooks and Huges (93) found the haemoglobin index of the Holstein-Friesians in U.S.A. to vary within 10.6 - 11.10. Manresa et al (90) attributed this low haemoglobin content of Holstein-Friesians in the Phillipines to the effect of higher environmental temperatures. Although Indian Nellore cattle have acclimatized completely to the environmental conditions in the Phillipines variations in the haemoglobin content of these animals have been reported by Manresa et al (94). They studied the blood of ten animals at intervals of 2½ hours. The averages of haemoglobin content for mature animals were found to be as follows:-

6.30 a.m.	-	9.81 gms. per 100 cc. of blood.
9 "	-	9.19 " " " " " "
11.30 "	-	9.11 " " " " " "
2 p.m.	-	8.92 " " " " " "
4.30 "	-	9.27 " " " " " "

They found a slight negative correlation (-0.226) between haemoglobin index and atmospheric temperature. In another study Manresa, Gomez and others (95) found a negative correlation (-0.183) between haemoglobin index and body temperature of the Indian Nellore.

Manresa and Orig (96) found also seasonal variations in the haemoglobin content of the Phillipine native cattle. They studied the blood content of three male and female native cattle over a period of one year at weekly intervals. Data presented by them show that the lowest values (7.8 - 7.9) occurred in the months of April, May and June and the highest values (11.2 - 11.3) occurred in the months of November - December. These authors did not find a correlation between haemoglobin content and body temperature of these animals. However they found that the haemoglobin index was slightly negatively correlated with atmospheric temperature.

In their investigations on Nellore cattle Manresa et al (90) also observed seasonal variations in the haemoglobin content of the blood, the index being higher during the cooler months of December, January and February than in the summer.

As regards calcium, phosphorus and sugar content of the blood of these animals the authors did not find any relationship with atmospheric temperature.

In conclusion they stated that "with animals already acclimatized to a given environment such as the Indian Nellore in the Phillipines, fluctuations in the blood composition take place without seriously affecting constitutional vigour."

The effect of sudden decrease in environmental temperature on the blood picture of cattle has been studied by Delaune et al[97]. They found that sudden falls in temperature produced sharp rises in leucocyte count but did not produce any change in erythrocyte number or haemoglobin content. A drop as great at $37^{\circ}F$ increased leucocyte count to as much as 26,750 whereas the normal was 9,500 - 11,000.

From these observations it appears that high atmospheric temperatures may lower the haemoglobin content slightly of the Zebus and possibly greatly of the temperate breeds. Since oxygen must be carried by haemoglobin for metabolic processes, the decrease in the haemoglobin content of blood must seriously affect the metabolism and hence the consistution of the animal. However, considering that other factors such as increase in body temperature and respiration rate of European cattle imported in the tropical countries, and also the poor nutrition leading to weak constitution of these animals, may directly or indirectly affect their blood composition, and also considering that the basic research in this line is inadequate, no conclusion can be arrived at regarding the influence of environmental temperature on the blood of cattle although there seems to be some indication that at least the haemoglobin content of the blood of dairy animals, specially European cattle may be directly or indirectly influenced by the higher tropical atmospheric temperature.

4. Metabolism of Dairy Cattle:

The term metabolism is commonly used to designate "the totality of the chemical and physical changes which the materials of the resorbed food, or of the tissues formed from them, undergo in being converted into the excretory products." (Armsby [98]). So metabolism is not simply a burning process of food materials but in reality a highly complex action of the living cells of the organism, still the final result is much the same in both cases.

In experiments on animal metabolism, usually the "basal metabolism" is determined. Basal metabolism is the energy metabolism when the animal is at complete rest and in "post-absorptive" condition. The time required to reach this post-absorptive state varied according to animal, eg. 12-18 hours fasting in men (Sherman [30]) and 48-72 hours fasting in cattle (Brody [99]).

Brody et al [100] have used another term "resting metabolism" in their studies on domestic animals. "Resting metabolism" differs from the "basal metabolism" only in that the animals are not in the post-absorptive condition. The resting metabolism measurements are made in the morning before the morning feeding, that is, 10-12 hours following the preceding regular evening feeding. Another important point is that basal metabolism does not include the heat increment of feeding (S.D.A. and fermentation heat) but the resting metabolism does, because the indigestion of food is still continuing. In dairy cattle Brody et al [100] found that the heat production of resting metabolism is 24-27% higher than the basal metabolic heat production.

There is a superior limit and a lower limit of environmental temperature beyond which the regulation of body temperature cannot be carried out by pyhsical means such as radiation, conduction and evaporation (cf. heat regulating mechanism). The only method by which the temperature of the animal can be maintained in a cold environment is an increase in the rate of generation of heat by chemical means and naturally the metabolic rate or basal metabolism value is increased.

In hens Winchester [101] and Kleiber et al [102] found that the fasting heat production is inversely correlated with atmospheric temperature. Similarly in cat (Armsby) [29] and dog (Rubner) [103] metabolic heat p oduction has been found to decrease with increasing environmental temperature.

Definite seasonal metabolic rhythm in humans has been reported although there is, as usual, considerable disagreement in details (Gustafson and Benedict) [104], (Griffith et al) [105], (McKay) [106], (Tilt) [107], (McGregor and Loh) [108], (Martin) [109]. In their studies on basal metabolism of women Hafkesbring et al [110] found that the metabolism was 5 p. c. higher in cold weather than that in hot weather.

In goats Brody et al [111] found a seasonal metabolic rhythm similar as in humans, the maximum occurring in early spring and the minimum in summer. In an earlier experiment (112) they obtained similar results with sheep. In an experiment with hog, under the conditions of controlled temperature and similar food throughout the period Capstick and Wood [113] found the critical temperature to be approximately 68.7 ^{o}F. At this temperature the basal metabolism was minimum and below this there was a linear increase in heat production with decreasing environmental temperature.

A few other workers, on the other hand, have noted an increase in metabolism at very high temperatures. This is of particular interest because Rogan and Richardson [63] and Hays[65] whose works will be cited later (cf. production) found, contrary to their expectation, that the fat content of cow's milk increased above 85° F. Hays believed that this was probably due to increased metabolism of the cows at higher temperatures.

In his observations on guinea-pig and dog Rubner[103] found that basal metabolism increased above and below 86° F in the former and 68° F in the latter.

McConnel and his associates[114] stated that contrary to what might be expected, metabolism of man increased with exposure to high temperatures. They found that there is a zone of minimum metabolism between 75° and 83° F and that the metabolic rate became excessive when the temperature of the environmental exceeded the body temperature.

In an attempt to study the effect of temperature on the basal metabolism of ruminants Magee[115] subjected a goat to various temperatures from 30° - 100° F. He found rather a long critical range of temperature for the goat, 55° - 70° F. As the temperature fell below 55° F metabolism increased slightly but gradually, and as the temperature rose above 70° F metabolism showed a pronounced gradual increase. He stated that below 55° F metabolism increased due to oxidation necessary to cope with the increasing heat loss and above 70° F metabolism increased owing to the gradually increasing efforts of the animal to promote heat dissipation by increasing respiration rate.

It appears from these observations that there is a rapid increase in basal metabolism with the decrease in environmental temperature. However, this is no proof that there will be a similar rise in metabolism of normally fed dairy cows under the farm conditions. No experiment has been conducted to study the effect of environmental temperature on the basal metabolism of fasting dairy cows. In producing dairy cows it is not also possible to measure basal metabolism at normal level of production because fasting profoundly depresses milk production (Washburn et al (116)). Another complicated, rather interesting situation, has been observed by Washburn et al (116) in their studies of basal metabolism of lactating cows. They found that the total heat production per day of a 820 pound cow was the same as that of the 1120 pound dry cow in spite of 300 pounds live-weight difference. It might seem that the extra energy in the small cow was expended for milk production. But this was not found to be the case because after three days' fasting, when the milk production of the small cow was very much reduced the heat production of the small cow with respect to body weight was not appreciably different from that of the large dry cow.

Washburn (117) suggested that a part of extra heat production during lactation may be essential for higher maintenance of the hypertrophid, active mammary gland and higher endocrine activity, which may continue even during starvation. These observations point out the difficulties in studying basal metabolism of producing dairy cows. However, a few general observations have been made on the metabolism of dairy cows under ordinary farm conditions.

Dice (53) in connection with his studies on barn versus shed cows in North Dakota during winter months, when the minimum environmental temperature went, several times, below zero degree F., stated that "milk cows on full feed, when housed in a cold stable, produce sufficient surplus heat over usual maintenance requirements to maintain body temperatures without using nutrients for that purpose." The large amount of extra heat production, in dairy cattle, due to feeding has been reported by several others (Jordan (118, Armsby[119], Brody[120]) (cf. production). In their observation with steers, Benedict and Ritzman[82] found that the total heat production of these animals, when kept on maintenance ration, did not increase when the temperature was lowered by even as much as 30 °F., but it did increase when the animals were kept on sub-maintenance ration, showing that the heat "increment due to feeding" at maintenance level was sufficient and could be utilized for maintaining body temperature.

It can be concluded, therefore, that the metabolism of well fed dairy cows is not affected by low temperature within reasonable limit. Unlike simple-stomached animals and probably other smaller ruminants, dairy cattle produce huge amounts of extra heat due to feeding, which can be conveniently used for the maintenance of body temperature at low environmental temperatures without increasing metabolism solely for this purpose. At higher temperatures, however, this surplus heat production aggravates the problem of heat disposal and seriously affect normal metabolism.

5. Food Consumption and Utilization of Dairy Cattle:

Consumption:

It has been said before that in ruminants, particularly in dairy cattle, large amounts of "extra heat due to feeding" is generated within the body. Bonsma (44) stated that this heat increment of feeding is directly proportional to the quantity of fodder consumed. It has also been stated before that this extra heat can be utilized by the animal for the purpose of maintaining body temperature under low atmospheric temperature conditions but at higher environmental temperatures, this heat is an extra burden to the animal and has to be dissipated. So it is quite natural to expect that a dairy cow will consume more at lower temperatures and much less at higher temperatures. In this respect Bonsma (44) found, in South Africa, that when the body temperature of the cow began to rise at higher atmospheric temperatures, the animal ate less so that the metabolic heat production might be reduced and that under such circumstances an animal of temperate origin which has been accustomed to higher level of feeding was affected most. Friesland dairy cattle which are large eaters and consequently more susceptible to over-heating under the conditions of high atmospheric temperatures, consumed too little for their production during hot spells and as a result the milk production immediately dropped during these periods.

Utilization:

From a three-year trial with beef cattle in Missouri, Waters (121) found that cattle housed in barns required 10.77 lbs. of D.M., cattle in open sheds required 10.25 lbs. and cattle in an open lot with no shelter other than wind-break and with corn stalks for bedding, required only 10.22 lbs. of dry matter for a pound of weight gain.

Thus he stated "The cattle confined in a barn at night and during stormy weather ate less, made smaller gains and less gain per pound of dry matter consumed than cattle that had access to an open shed or less economical gains than did those which were in an open lot without shelter and with pile of corn stalks to lie on." This observation made by Waters on beef cattle was confirmed by similar results obtained by Mairs and Tomhave (122) and Cochel and Doty (123) at Pennsylvania; and Potter and Withycombe (124) at Oragon. Dice (125) made similar observations on dairy cows at North Dakota. He compared the cows kept in dairy barn with similar groups kept in open shed. The average temperature of the barn for two trials was 48 °F., and 28.3 °F for the shed. The results obtained by him has been arranged in the following table:

TABLE 12.

	1st Trial		2nd Trial	
	Barn Cows	Shed Cows	Barn Cows	Shed Cows
Aver. temp.	48°F	28,3°F	48.0°F	28.3°F
D.P. for 1lb. fat	2.499 lbs.	2.18 lbs.	2.397 lbs.	2.253 lbs.
D.P. " " milk (F.C.)	1.0071 "	0.0871 "	0.0951 "	0.0897 "
T.D.N. " " fat	16.03 "	14.02 "	18.38 "	17.31 "
T.D.N. " 1 lb. milk (F.C.)	0.6484 "	0.5644 "	0.7285 "	0.6924 "
Test of milk	3.88%	4.53%	3.695%	3.98%

The above table shows that shed cows used less D.P. and T.D.N. for every pound of butterfat than the barn cows. Also when the milk is corrected for 4% fat the shed cows required less D.P. and T.D.N. for every pound of milk than the barn cows. So the shed cows exposed to lower atmospheric temperatures utilized food, as measured from the D.P. and T.D.N. values, somewhat better than the barn cows.

It could be at least said that the comparatively lower temperatures of the shed had no adverse effect on the food utilization of the producing cows. He (53) continued this observation during four more seasons, the shed cows and barn cows being reversed in alternate months during the last two seasons. During these trials the cows were fed corn silage and alfalfa hay in proportion to body weight, and fed grain according to production. The results obtained were as follows:

TABLE 13.

Digestable nutrients used for production of milk.

Separate groups of cows.

	1st Season		2nd Season	
	Barn Cows.	Shed Cows.	Barn Cows.	Shed Cows.
Mean temp. °F.	45.3	31.80	51.16	24.87
Lbs. protein for 100 lbs. 4% milk.	9.36	8.99	10.49	9.26
Lbs. T.D.N. " " " 4% milk.	71.19	68.26	80.30	70.99

Same cows in barn and shed - alternate months.

	3rd Season		4th Season	
Mean Temp. °F.	52.2	25.95	53.90	34.96
Lbs. Protein for 100 lbs. 4% milk.	10.15	10.03	9.32	9.22
Lbs. T.D.N. " " " 4% milk.	79.04	78.12	68.93	68.29

Summary of all trials.

Lbs. Protein for 100 lbs. 4% milk.	9.83	9.37
Lbs. T.D.N. " " " 4% milk.	74.86	71.41

The table shows soemwhat better utilization of digestible nutrients by the shed cows than the barn cows. Also the summary of production and weight gains presented by the authors showed that the shed cows produced more 4% milk (82,882 lbs.) than the barn cows (82,453 lbs.) and also gained more in weight (2621 lbs.) than the barn cows (980 lbs.). So the better utilization of the digestible nutrients by the shed cows was not at the cost of production or weight gain.

In conclusion the author stated "that cows housed in a cold shed require anything somewhat less protein and T.D.N. for milk and butterfat production than the cows in the dairy barn."

Bonsma (44) in South Africa observed the detrimental effect of higher atmospheric temperatures on the food utilization of European cattle. He stated that the ability of these animals to convert large quantities of fodder into flesh and milk is suppressed by the high atmospheric temperature which causes a feverish rise in the body temperature and also a loss of appetite.

At the Messina Experimental Station Bonsma (88) attempted to stimulate the growth of animals by increasing the protein content of the diet but this did not result in any marked improvement in the rate of growth. He concluded "It is clear that in hot areas where animals experience great difficulty in eliminating surplus heat, additional protein in the diet fails to stimulate growth unless methods are adopted at the same time to facilitate the expulsion of surplus heat." He suggested this could be done in the case of stud bulls by giving the animals a shower bath at about 10 a.m. in the morning or by keeping them in cool, well ventilated stables. As reported by workers in India

(Minnet and Sinha)[237] shower bathing of producing cows and buffaloes at mid-day during the summer could be practised with profitable results.

That higher environmental temperature is an important factor affecting food utilization and consequently weight gain, is also borne out by Bonsma's observation on the dry mature cows running on the ranch in South Africa. He found that these animals gained in weight and built up body tissues during the late autumn and early winter when the feed was scarce and nutritive value of the grass was considerably low rather than in the early and mid summer when the pasture had better growth and nutritive value was higher. No doubt that the growth of the animals during the cooler months in spite of the relative scarcity and poor quality of the pasture in this period, was due to the better stimulation of the physiological functions of the animals and hence better utilization of the available feed. Similarly he found that on the high veld where the climate is suitable, the growth of cattle was retarded due to lack of feed whereas on the tropical low veld where the average annual temperatures are above 65 ^{o}F., the growth was retarded because the animals were unable, under the conditions of the high environmental temperatures, "to metabolise properly sufficient food for normal existence."

It is evident from these observations that higher environmental temperatures have a detrimental effect and lower environmental temperatures, probably within reasonable limits, have rather beneficial effect upon the food consumption and utilization of the dairy cattle.

6. Grazing performance of dairy cattle:

It is recognized that grazing the dairy cow on good pasture is the cheapest way of getting the most out of her. So it would be interesting to know how the environmental temperature, such as warm or cool weather, influences the grazing of the dairy animals but the published reports on the activities of dairy cattle while on pasture, are relatively few.

Seath and Miller (85) made a detailed study of the effect of warm weather on grazing performance of milking cows during the summer at Baton Range, Louisiana. Three Jersey and three Holstein cows were used and observations were madeduring five 24-hour periods. Cows had access to relatively good permanent pasture, well provided with shade, which consisted largely of Bermuda, Dallis and carpet grasses. The cows were brought to the barn for morning (5.45 a.m.) and afternoon (3 p.m.) milkings. During the period of observations the atmospheric temperatures taken in the shade varied widely - 72 - 86 °F during the days and 62 - 81 °F at nights. The summary of the results of their observations is given in the following table:

TABLE 14.

Grazing and air temperature relationships (average of 6 cows for daytime and night).

24-hour periods.	Average air temperatures.		Hours in Pasture	Hours spent grazing or not grazing.					
				Daytime		Night		Daily totals	
	Daytime	Night		Grazing	Not Grazing.	Grazing	Not Grazing.	Grazing	Not Grazing.
Days	°F	°F							
1	86	81	17.2	1.9	5.7	6.5	3.1	8.4	8.8
2	85	71	17.3	1.8	5.5	6.2	3.8	8.0	9.3
3	82	73	17.2	2.8	4.4	5.1	4.9	7.9	9.3
4	72	62	16.9	4.5	2.7	4.7	5.0	9.2	7.7
5	72	62	16.8	4.5	2.8	5.0	4.5	9.5	7.3

The grazing results of the first two days of observations appear to be representative of how milking cows perform on pasture during the relatively warm weather. The daytime period consisted of the time after the cows entered pasture in the morning (7.15 a.m.) and they left in the afternoon (2.35 p.m.). During this period the cows grazed only 1.9 hours the first day and even less, 1.8 hours, the second day. As contrasted to this, time spent not grazing (mostly in shade) was 5.7 hours for the first day and 5.5 hours the second day. The daytime atmospheric temperatures for these two days averaged 86° and 85° F., respectively. The night totals for grazing - after p.m. milking until morning milking at 5.45 a.m. for these first two nights were 6.5 and 6.2 hours respectively. Thus grazing at night for these warm days equalled more than three times that for the daytime. For the third day the grazing record showed an intermediate status. Daytime grazing increased approximately one hour to a total of 2.8 hours while grazing at night fell off 1.1 hours. On the fourth and fifth days daytime grazing increased to 4.5 hours for each of these two days. Night grazing decreased to 4.7 and 5 hours respectively for these days. The results on the fourth and fifth days as compared with first and second days, give some evidence of how cooler weather influences grazing habits of dairy cows. The air temperatures during these two days all through were much lower than those during the first two days. As a result the cows spent more time grazing during the daytime on the last two days, nearly 2.4 times the average for the first two warm days. Also the cows spent less time grazing at night during the last two days as compared with first and second days. In spite of this decrease in time spent in grazing during the night, the total grazings during twenty four hours for these cooler days were 9.2 hours and 9.5 hours respectively, or more than one hour longer than for the first three days. Apparently on the first two days the grazing activities of the cows greatly increased during the night because the air temperature at night were comparatively lower than at daytime. On the last two cooler days, however, the cows showed increased activities during the daytime.

The results obtained by Seath and Miller cannot be reasonably compared with those obtained by other workers, because, apart from the size, production etc. of the cows, the air temperatures during the periods of observation have not been noted.

Atkeson et al (126) made observations with milking cows during the daylight periods only and again in his 24-hour period observations he used dry cows and heifers. Hodgson (127) made observations during daylight hours only. According to Atkeson et al the dry cows spent on good pastures about seven hours in grazing, the greater portion of the time (4.3 hours) occurring at daytime and 2.7 hours at night time. Seath and Miller rather found that on cooler days the cows spent more or less equal time in grazing during the day and at night. This is so without taking into consideration the interferences in grazing during the milking hours. Considering the length of the time the cows were on the pasture during the day (approximately 7½ hours) and at night (approximately 9½ - 10 hours) the cows grazed longer during the daytime than at night on the two cooler days. On the percentage basis about 23% grazing took place during the day and about 77% at night on the first two warmer days in Seath and Miller's observations. On the other hand, on the two cooler days 46% grazing occurred at day and 54% at night. Hancock and Wallace (128) in New Zealand, however, found that 58% grazing took place between 7 a.m. and 3 p.m. and 42% between 5 p.m. and 4.45 a.m. That the cows spent comparatively less time during the day than at night even on the cooler days in Seath and Miller's observation could be possibly due to the reason that the day temperatures during these two days, although comparatively cooler, were not cool enough for the cows. Seath and Miller's observations, however, conclusively show that higher atmospheric temperatures (above 72 °F during the day) significantly decsease the time spent in grazing by dairy cows during the daylight hours and increase the night grazing and also depress the total grazing.

Bos Taurus versus Bos Indicus:

Differences have been observed between Bos Taurus and Bos Indicus animals in their grazing performance under tropical temperatures. Using Aberdeen Angus, Brahman cows and F_1 and F_2 Angus x Brahman cross-bred animals Rhoad (73) at Jeanerette, studied the effect of summer temperatures, as well as solar radiation and shade on the grazing habits of these animals. Observations were made on a warm overcast day, on a clear and calm day and on a clear day with gentle breezes. Atmospheric temperatures during these days varied from 74° to 94° F., the highest occurring in the afternoon (12 - 5 p.m.) and the lowest in the morning (6 a.m. - 12 noon). The results obtained with the same animals on these three different days were as follows:

TABLE 15

Grazing habits of Aberdeen Angus, Brahman and cross-bred cattle.

Type of animal	No. of animals	Av. percent. of day: Grazing	Resting: Sun	Resting: Shade
Warm overcast day.				
Aberdeen Angus	2	73.9		26.1
$\frac{3}{4}$ Angus - $\frac{1}{4}$ Brahman	2	60.3		39.7
$\frac{1}{2}$ Angus - $\frac{1}{2}$ Brahman	2	64		36
Purebred Brahman	2	74.5		26.5
Clear and calm day.				
Aberdeen Angus	2	49.5	.7	49.8
$\frac{3}{4}$ Angus - $\frac{1}{4}$ Brahman	2	54.0	2.7	41.3
$\frac{1}{2}$ Angus - $\frac{1}{2}$ Brahman	2	53.4	32.3	14.3
Purebred Brahman	2	76.5	23.5	-
Clear day with gentle breeze.				
Aberdeen Angus	2	69.1	2.1	28.8
$\frac{3}{4}$ Angus - $\frac{1}{4}$ Brahman	2	60.6	2.8	36.6
$\frac{1}{2}$ Angus - $\frac{1}{2}$ Brahman	2	80.2	19.8	-
Purebred Brahman	2	82.8	17.8	-

The table shows that, on a warm overcast day (with no sun throughout the period of observation) the $\frac{3}{4}$ Aberdeen Angus animals spent less time grazing than even the purebred Aberdeen Angus type. The author attributed this to the small size of these animals weighing about 200 lbs. less than other animals. Being small the animals might have acquired a fill quicker. On this day there was practically no difference between the purebred Angus and purebred Brahman animals.

Compared to this it is seen that on the bright sunny day the purebred Angus spent the least time and the purebred Brahman the most time in grazing, and the cross-bred animals were intermediate. The purebred Angus spent the most time in the shade, then the $\frac{3}{4}$ Angus, then the half-bred, while the purebred Brahman did not seek the shade when not grazing but remained in the open pasture. The purebred Brahmans spent the least time resting. It is clear from the table that on a bright warm day the $\frac{3}{4}$ Angus animals were similar to the purebred Angus in grazing habits and the half-breeds were similar to the purebred Brahmans. Rhoad stated that the purebred and $\frac{3}{4}$ bred Angus animals not only utilized less total time in grazing under bright summer conditions, but also grazed more frequently than the $\frac{1}{2}$-bred and specially the purebred Brahmans. This might be possibly due to the reason that, because the pure-bred and the $\frac{3}{4}$-bred Aberdeen Angus animals were less efficient to stand the hot sun, they could not graze for long at a stress and therefore had to graze more frequently in an attempt to satisfy their appetite.

The table further shows the effect of gentle breeze on a bright hot day. Light breezes increased the time spent in grazing and decreased the time resting for all groups but more so for the purebred Angus and cross-bred animals. This favourable effect of light wind on the grazing of cattle under high atmospheric temperature conditions has been noted by Bonsma[(44)] as well. He further states that on hot days the animals graze against the wind while on cool days they graze with the wind. Probably gentle breezes have a cooling effect on the animals. However as the cows have no sweat glands and as there is very little evaporation from the skin gentle breezes cannot cool these animals appreciably unless the air temperature is lower than the skin temperature (Brody)[(129)]. In the tropical countries the skin temperature of the animals out in the sun do rise very quickly and may be as much as 25 - 30 °F higher than the air temperature (Bonsma)[44] and then light wind must have a cooling effect on these animals.

Bonsma[44] found similar genetic differences between Africaner breed and exotic beef breeds of European origin in their grazing performance under the hot South African conditions. The atmospheric temperature during the period ranged from 81 to 101 °F. In addition to the percentage of day grazing by different breeds, he noted also the number of times they defecated, urinated and the ruminations per minute. The results obtained by him are given in the following table:

TABLE 19.

Breed	%age of day grazing	No. of times defecated & total weight (lbs).		No. of times urinated	Ruminations/minute	
					A. M.	P. M.
Africaner	89%	6	16.5	1	49	51
Hereford	79%	6	15.5	2	51	55
Shorthorn	78%	5	10.25	2	57	0
Aberdeen Angus	75%	1	4.25	0	54	0

The table shows that the Africaner grazed for a longer time than the exotic breeds. Further the exotic breeds, Shorthorn and Aberdeen Angus, ceased to ruminate altogether after the mid-day when, it has been stated, the air temperatures considerably increased. These animals particularly Aberdeen Angus tended to defecate and urinate less than the other animals. In these respects Hereford seemed to be least affected among these exotic animals. This is quite likely considering that the body temperature and respiration rate of the Hereford animal is much less affected by high atmospheric temperatures than the Shorthorn and Angus animals (cf. body temperature, respiration and pulse rate).

Conclusion can be made from these observations that higher environmental temperatures (above 70 °F) adversely affect the grazing performance of dairy cattle and that in the tropical countries where, in addition to the high atmospheric temperatures, the solar radiation is intense, the cattle breeds of European origin are very much less efficient as grazing animals than the Bos Indicus cattle.

The increased activity of cows at night following warm day indicates the importance of allowing cows access to good night pastures. The plan of leaving cows overnight on a poor paddock so that they will be convenient to the milking shed in the morning, is most certainly a poor management practice, at least during the warm summer period.

7. Endocrine Glands:

It has not yet been established to what extent environmental temperature affects the functions of ductless glands. Comparatively little research work excepting some general observation has as yet been carried out in this direction.

According to Bonsma (44) great fluctuations in temperature such as are found in continental Europe, have a stimulating effect upon the ductless glands. He states that one of the main functions of these glands is to regulate the body metabolism and maintain the body temperatur and that fluctuations in the atmospheric temperature consequently demands increased activity on the part of these glands. If the temperature fluctuates only slightly as in the case of many cattle ranching areas in the tropical and subtropical countries, these glands do little work and long periods of heat have a suppressive effect upon them.

Pituitary:

Bonsma (44) states that the secretion of the anterior pituitary gland is closely connected with the development of the bony structure or skeleton. In the tropical and subtropical countries the function of the pituitary gland is suppressed and as a result the animals in these countries have smaller and weaker bony structure. Furthermore, the heightened sexual activity of animals during the spring and autumn has been attributed to the stimulative effect of weather conditions upon the pituitary gland during these seasons.

The detrimental effect of high temperature on the production of the anterior pituitary hormone necessary for lobule-alveolar growth of mammary gland has been observed by Mixner and Turner (130). They injected in mice progesterone and anterior pituitary extract seperately each accompanied by oestrone in mice kept at 77° and 95° F. The response to progesterone was much diminished at the higher temperature whereas the response to pituitary extract was unaffected. They concluded that progesterone (with oestrone) promotes mammary lobule-alveolar growth by stimulating the pituitary to secret an appropriate hormone and that high temperature inhibits the production of this hormone.

Thyroid:

The effect of temperature on thyroid has been observed by several workers. Exposure to cold causes a compensatory increase in thyrotropin production which leads to marked morphological and functional stimulation of the thyroid. Thus rats kept a temperature of 30.2° F for about one month, usually have greatly enlarged thyroids which exhibit histological signs of hyperplasia, similar to those produced by thyrotropin injection (Selye)[131]. It is believed that the resulting increase in thyroid-hormone production plays an important role in the maintenance of body temperature and adaptation to cold by facilitating compensatory heat production through an increase in tissue metabolism.

Leblond and Gross[132] found that throidectomized rats die within a week whereas normal rats survive for several weeks or months when exposed to 2° C (35.6° F).

The stimulating effect of cold and the suppressing effect of heat on thyroid and throxine production with its consequent effect on metabolism have been noted by others in rats (Dampsey and Astwood[133]; Dampsey et al[134]; Ring[135]) pigeons (Riddle[136]), rams (Berliner and Warbriton[137]; Mackenzie and Berliner[138]), man and other animals (Dampsey and Astwood[133]). In rams, the hypofunctioning of the thyroid under summer temperatures leads to summer-sterility as indicated by the increased number of abnormal spermatozoa in the semen, the degeneration of germinal epithelium with consequent failure of spermatogenesis (Bogart and Mayer[139]).

The diminished thyroid activity resulting in sterility in rams occurs at a comparatively lower temperature than is necessary for affecting the spermatogenetic functions of the testis through raising scrotal temperature (cf. effect of temperature on testicular function). Administration of thyroxine or thyroid active protein orally or by injection alleviates the symptoms of summer sterility in rams.

In addition to reproduction, the secretion of thyroid gland has been reported to play an important role in growth and lactation (Schultze and Turner[140]) Ralston and others[141], by injecting thyroxine in lactating cows, obtained an increase in the production of milk (13.6 p.c.) and fat (22.5 p.c.)

Testis:

Testis hormone is necessary for normal reproduction of the male (cf. factors affecting fertility). As regards the influence of temperature on the production of this hormone the observations are not in full agreement. Moore[142] stated that in cryptorchid and experimentally produced cryptorchid rats and guinea pigs in which the testes were subjected to abdominal temperatures which are higher than scrotal temperatures the secretion of testis hormone was normal. Jeffries[143] found that the testes of rats confined in the abdomen for sixty days, although in a degenerative state, produced as much hormone as did the normal testes. Nelson[144], however, continuing his experiment with rats for still longer periods noted a gradual decline in hormone secretion with consequent detrimental effect on other organs including pituitary gland, thus showing that the temperature affecting one gland may indirectly affect other glands and disturb the endocrine balance. Hanes and Hooker (145) made observations on pigs. In contrast to the other workers cited above who used, as criteria of hormone production, hormonally regulated characters in their cryptorchid animals, these latter workers measured the quantity of hormone itself by assaying them in bird units. The values obtained by them indicate that in the pig the cryptorchid testes contain approximately one half as much hormone as do the scrotal testes.

Adrenal:

Selye (131) states that extreme heat or cold, in addition to other factors, affects the functioning of the adrenal medulla as well as cortical cells and that long continued exposure to these factors causes histologic signs of increased adrenaline and corticoid hormone secretion.

The influence of temperature on the functions of other glands is not known. However all this evidence, although not conclusive in many cases, indicate that high temperature probably affects and low temperature stimulates the endocrine glands and that temperature through its direct effect on any particular gland may disturb the endocrine balance. Since the ductless glands play an essential part in growth, reproduction and production, the influence of temperature on these glands may have a bearing on the performance of an animal.

B. INFLUENCE OF TEMPERATURE ON GROWTH OF DAIRY CATTLE:

Apart from heredity many environmental factors affect growth, that is, the rate of live-weight gain. Nutrition is the most important factor and other important factors are climate, season, shelter, shade and disease. (McMeekan et al)[46]. Of the climatic factors temperature is important.

Animals other than cattle:

In chicks Winchester and Kleiber[47] and Kleiber and Dougherty[48] found under controlled conditions that both higher and lower environmental temperatures depressed the growth. The maximum growth occurred at 21 ^{o}C (69.8 ^{o}F) and above and below this temperature the growth of the chicks gradual y declined. Kempster and Parker[49] found a precipitate decline in the growth of chickens during a hot July when the maximum daily temperature rose to 110 ^{o}F and the mean daily temperature to 98 ^{o}F. They found a definite negative relationship between the environmental temperature and the growth of chickens within the temperature range of 50 - 110 ^{o}F.

McKay and Brown[50] discussed literature on the seasonal growth in children. There is considerable disagreement in details but the fact appears to be that the growth in children of varying ages between 5 - 15 years tends to be most rapid (about one pound gain in weight per month) during autumn and least rapid (about ¼ pound per month) in the spring months. Seasonal variations in food supply, sunshine and temperature were held responsible for variations in weight increase among children.

Interesting observations have been made by Ogle[51] in mice. He compared the growth rate of mice kept in cold room and hot room. Unfortunately the temperatures have not been mentioned. At the beginning of the experiment the hot room group averaged 8.64 gms. and the cold room group averaged 8.35 gms. By the end of the experiment the hot room group averaged 20.79 gms. whereas the cold room group averaged 27.62 gms. with steady increase in weight all through the period. Together with these different rates of increase in body weight there were found significant differences in the growth of the body skeleton. The hot room group had shorter bodies and longer tails than the cold room. $\left(\frac{\text{Body length (cm.)}}{\text{Body weight (gm.)}}\right)$ ratio of the hot/room group averaged greater (0.432) than the cold room group (0.324). It appears from this experiment that cooler temperatures stimulated the increase in weight and body length at a more rapid rate and uniformly while the higher temperatures depressed it. Another interesting point to note here is that the rate of skeleton growth in the hot room group continues at the expense of rate of gain in weight. That is rather expected because basic needs such as formation of skeleton must be met first. Similar stimulating effect of coolness (65 - 80 ^{o}F) and depressing effect of higher temperature (89 - 92 ^{o}F) on the growth of mice was observed by Mills (52). The effect of very low environmental temperatures on the growth of mice has not been studied but undoubtedly the high temperatures, higher than upper critical (81 - 84 ^{o}F) (Brody (27)), definitely affect their growth.

Cattle:

Dice (53) compared the weight gains between cows kept in the closed stable versus cows kept in the open shed. The observations were made during successive winters in North Dakota. During the preliminary trial which lasted for two months November - December a group of five cows kept in the barn was compared with a similar group of cows turned out in the cold morning and left out all day. The mean temperature for November was 22°F., and for December was 9°F., the minimum going below zero several times. It was found that the barn cows gained 184 pounds in live-weight and the shed cows 207 pounds during the two months. To check these results other groups of shed cows were turned out night and day during next February - March and during November - December and were compared with similar groups kept in the dairy barn. The mean temperatures for February and March were 23°F and 27°F respectively and for November and December 30.4 and 19.8°F respectively. The weight gains of the shed and barn groups are given in the following table:

TABLE 16.

Weight Summary.

	No. cows	Barn cows	Shed cows
		Lbs. gain or loss.	Lbs. gain or loss
Feb. - March	3	- 92	+ 61
Nov. - December	4	+340	+401
Total	7	+248	+462
Av. gain per cow.		+ 35	+ 66

In another two trials lasting for five months each during the winters of next two years the results were as follows:

TABLE 17.

	1st trial		2nd trial	
	Barn cows	Shed cows	Barn cows	Shed cows
Lbs. gain in weight	292	426	459	556
Mean temp. °F.	45.3	31.8	51.6	24.8

During all these trials the cows were fed grain and silage. This experiment was further continued during the next two seasons and in these trials the two groups were reversed in alternate months to overcome any of the inevitable differences between the groups. The cows were fed corn silage and alfalfa hay in proportion to their body weight and were fed grain according to their production. The weight gains for the two groups during the two seasons were as follows:

TABLE 18.

Same cows in barn and shed - alternate months.

	1st season		2nd season	
	Barn cows	Shed cows	Barn cows	Shed cows
Mean temp. °F.	52.2	25.9	53.9	34.9
Lbs. gain in weight.	+363	+440	-134	+1199

Data presented in these tables show that the cows in the cold shed where the atmospheric temperature was much lower than in the barn, tended to gain somewhat more body weight than other cows or the same cows when kept in a standard dairy barn. The author concluded that the dairy cows when well fed and sheltered from the wind, snow or rain and have a dry place to bed down "Can withstand exposure to cold temperature."

Dice (54) also made observations on yearling heifers during three seasons. He housed one group in open shed where the average temperatures were below freezing and another similar group in a closed shed where the temperatures were usually above freezing. From the trials during the first two seasons he found that the heifers in the closed shed on the average put on more weight, and grew better, as indicated by the gain in height at withers, than the heifers in the open shed. Results obtained during the third year did not confirm this observation. However, in each of the three years the closed shed heifers made the best gains in skeletal growth. The details of the experiment are not given. However, it appears that the young calves, unlike the cows, are somewhat sensitive to excessive cold.

Comparative observations have been made on the growth of calves belonging to native tropical breeds and temperate breeds imported in the tropics. It is generally true that the larger breeds of cattle come from temperate regions where food is available in abundance and that the smaller breeds have originated in countries less favoured in this respect. It is also true that when a breed is taken from a poor to a rich region or vice versa, it increases or decreases in size with succeeding generations. This occurs (Carneiro and Rhoad [55]) when the large European breeds are transported to the warm tropical climates where there is an abundance of forage during the rainy season but a shortage during the dry season. The tropics are also characterised by a lack of forage rich in proteins and, in some regions, by a lack of minerals essential for full growth (Hammond [56]; Kaura [24]). In addition, the growth of cattle suffers from the influence of environmental factors other than nutritional.

Carneiro and Rhoad [55] reported on the development of calves in Brazil where the climate is tropical. In their experiment 103 calves were kept at various stations and used for weight analysis at various ages. The calves were cross-bred Holstein - Zebus, purebred Holsteins and purebred Brown Swiss. The calves from birth were reared under ideal conditions and sufficient nutrients in balanced proportions were supplied all through. The authors compared the data obtained by them for Holstein and Brown Swiss calves, with the normal for the breeds. The figures presented by them show that the mean weight of the calves at birth, as compared with the normal, was low for the purebred Holstein and Brown Swiss. The difference, however was not very great. Notwithstanding lower weight at birth the calves developed at normal rate until the fourth month of age when growth began to decline. This decline was accentuated after the sixth month. Thus the offspring of imported cows born in Brazil reached only 220 kgms. (compared to 253 kgs. for normal) at twelve months of age. Their data (see figure 11) further show that, under similar conditions, the growth of Holstein-Zebu cross-bred calves in relation to the live weight of their dams, was even above the normal for the Holstein breed.

The authors concluded that environmental factors other than nutrition and care were responsible for the subnormal development of the purebred Holstein and Brown Swiss calves in the tropics. No doubt, of these environmental factors high tropical temperature is the important one.

Djjakov[57] reported that for economy of fuel and labour and to develop young stock resistant to low temperatures the calves on the Karavaevo Pedigree Farm (U.S.S.R.) are reared in the following way. The animals are kept from birth in untreated byres where in winter the temperature may be as low as -15° to -20°C (5° to -4°F). From early spring until late autumn the calves are kept in the open. The pregnant cows and the newly born calves are well fed and well managed. He reported that 42 calves

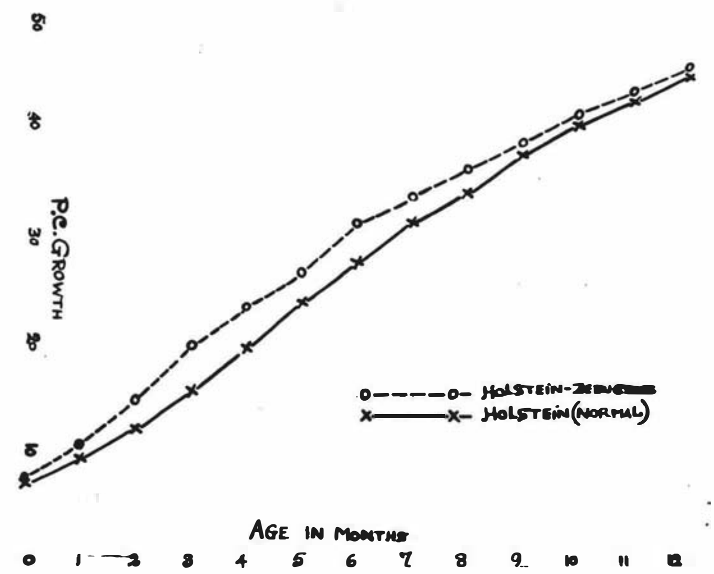


FIG. 11.

Growth of calves in relation to weight of adults, drawn from Carneiro and Rhoads' data (55).

born on the farm in winter 1938 weighed 37.4 - 37.8 kg. at birth and grew normally with a daily gain in live weight of 723 - 1019 gms. Newmann[58] made observations on the influence of stable temperature on the growth of calves and their hair covering. Three groups of calves (25 in each) were used in a 90 day experiment. Group 1 calves were reared at temperatures of 12 - 17 $^{\circ}$C (53.6 -62.6 $^{\circ}$F) at 1 metre from the ground and Group 2 calves at temperatures varying from -3° to +10° C (26.6 - 50.0° F) at one metre from the ground (stall not heated). Group 3 calves were reared at the same temperature as Group 1 up to 15 days of age, after which they were kept under the same conditions as Group 2. All groups received the same rations. During the period of 10 - 90 days of age, Group 2 made the biggest weight increases and at 80 days had the longest hair covering, there were also fewest cases of sickness in this group. Group 1 calves made better gains than Group 3 but were inferior to the latter in regard to hair covering and health. The breed has not been stated and the details of the experiment regarding the controlling of the stable temperature and grouping of calves have not been mentioned. However, it appears that lower temperatures (-3 to 10 $^{\circ}$C) stimulated better weight gains and hair growth and health; and that acclimatising the calves first to relatively higher temperatures (12 to 17 $^{\circ}$C), although only for a short period, and then shifting them to lower temperatures (-3 to 10 $^{\circ}$C) affected their weight gain but the lower temperatures later on stimulated hair growth.

Apparently little investigation on the effect of temperature on growth of dairy cattle has so far been made. However, from the observations that have been cited above it could probably be said that higher temperatures as occur in the tropics, affect adversely the growth of dairy cattle, particularly of European breeds, and that low temperatures within reasonable limits do not affect, rather stimulate growth. However, young calves which are unable to consume much roughage and produce much extra heat "due to feeding" and whose coat has not fully developed, should probably be protected from severe cold and rough weather.

C. INFLUENCE OF TEMPERATURE ON FERTILITY AND REPRODUCTION OF DAIRY CATTLE.

When we speak of animals being fertile, we mean that they are capable of successfully reproducing themselves. It is hardly necessary to stress the importance of fertility in dairy cattle. Because every year the older animals in a herd are to be replaced by younger ones, the chief aim of a dairy farmer must be to have animals of persistent fertility. Any failure in the reproductive capacity of his dairy stock will mean economic loss. So it will be interesting, particularly for a dairy farmer in a tropical country to know whether environmental temperature has any effect on the fertility of dairy cows.

Under wild conditions cattle breed at a more or less definite season of the year as do many wild animals. Domesticated cattle, however, have no definite breeding season, they will breed any time of the year but their breeding efficiency and reproductive capacity or fertility are not the same all round the year. It is generally agreed that it is easier to get a cow in calf in spring than in autumn. It appears, therefore, that there is a seasonal influence on the reproductive efficiency of cattle.

1. Factors affecting fertility:

The reproductive efficiency or fertility of an animal is influenced by several internal and external factors. The internal factors are: (1) the sex glands, (2) the endocrine glands, (3) genetic influences and (4) age of the animal etc.

The external factors affecting fertility are related to the environment and the supply of food. External factors are: (1) plane of nutrition, (2) disease, (3) climatic factors, (4) management and (5) breeding method (McMeekan[177]). Some of these external factors play a role in the fertility either directly or indirectly as they affect the internal mechanism.

Internal factors:

The sex glands - these are the testes in the male and the ovaries in the female. The primary organ in the male reproductive system is the testis which has two distinct functions - (a) the elaboration of spermatozoa or spermatogenesis and (b) the production of internal secretion. Seminiferous tubules are the seat of sperm production. Various factors such as seasonal and nutritional can cause degeneration of these tubules and consequently the production of normal sperms.

The internal secretion of the testes or the testis-hormone controls the function of the accessory sex glands and ducts and also the sex desire. The testis-hormone is also responsible for prolonging the life of spermatozoa within the epididymis (Anderson[178]). Therefore the normal functioning of the testes - secretion of hormone and spermatogenesis - is the most important factor for the fertility of the male. The effect of temperature on the testicular functions will be discussed later. The effect of temperature on testis hormone has been dealt with before (cf. "Endocrine glands".)

Ovary:

Although the ovary is similar to the testis in that it is concerned with the production of germ cells and sex hormones, the functionsof the testis are simple by comparison. The chief duty of the testis is the production of large numbers of viable spermatozoa, whereas the ovary is concerned not only with the production of viable ova but also with the nourishment of the developing embryo. The ovarian hormones, directly or indirectly are responsible for the development of vagina, uterus, the nourishment of the factus, the development of the mammary glands and perhaps to some extent, the actual secretion of milk (Rice[179]. The details of the parts played by ovary are not, however, within the scope of the present purpose.

Endocrine glands - These glands control to a great extent the functioning of the gonads either directly by secreting hormones which act on gonads or indirectly through affecting the metabolic functions of the animal. Of the endocrine glands, the pituitary and the thyroid are important so far as fertility is concerned. The effect of temperature on the thyroid and pituitary relations has been dealt with elsewhere (cf. Endocrine glands). Other internal factors such as heredity and age of the animal are independent of the temperature and so do not come into this discussion.

The external factors affecting fertility include the plane of nutrition, the climatic conditions, seasonal changes, management, such as exercise, and disease etc. The importance of plane of nutrition in fertility is well known. The low plane of nutrition affects the fertility enormously and a very high plane of nutrition, on the other hand, may lead to a condition of adiposity which is very common cause of infertility. Very fat animals do not come in season in a marked way, and when they do come in season the periods are apt to be irregular and likely to be missed, or the animals may fail to breed al-together. The climatic and seasonal factors include temperature, humidity, light weather conditions etc. We are particularly concerned with the effect of temperature on fertility.

Temperature may exert an indirect effect on the fertility or breeding efficiency through its influence on the supply of feed. In the tropical countries, particularly the high temperature conditions during the summer, are associated with drought and poor growth of pasture. As a result the animals are maintained on a low plane of nutrition during this period. The low plane of nutrition affecting the nourishment of the animals and probably the normal glandular functions will have adverse effects on fertility. Also under nourished animals with poor resistance become an easy prey to diseases which undoubtedly affect the reproductive efficiency. So temperature, besides acting directly, exerts its influence indirectly through other channels.

Many workers have studied the effects of temperature on the fertility of animals but most of the experiments have been conducted on the smaller animals such as rats, guinea-pigs, rabbits, sheep etc. and relatively few observations have been made on the dairy cattle. However the results obtained with smaller animals may possibly be applicable in dairy cattle.

2. Effect of temperature on testicular functions:

Moore[180] stated that temperature is very important for "reawakening" of reproductive activity of animals.

In rams it has been observed in Australia (Gun and Sanders[181]) and in Missouri (Mackenzie and Berliner[182]) that high summer temperatures lead to the degeneration of the semen quality. In hotter districts degeneration may be so marked that normal spermatozoa may be entirely absent in the semen.

Effect similar to high atmospheric temperatures have been produced by scrotal insulation (Phillips[183][184]). When the testis of a ram is wrapped with bags, the normal heat loss is prevented, the scrotal and testicular temperatures rise and in a few days the germinal epithelium and seminiferous tubules degenerate. The testicular functions recover after insulation if it is not continued too long.

Phillips[184] found that it took about three weeks for the spermatogenetic functions to recover after four weeks' insulation. In guineapigs, after a brief exposure (15 to 30 minutes) to high temperature, 46 ^{o}C (114.8 ^{o}F) to 47 ^{o}C (116.6 ^{o}F), the recovery period was about 12 days (Young[185]). In natural or experimental cryptorchid animals - dogs (Griffiths[186]; Crew[187]), rats and guineapigs (Moore[188]), rams (Moore[189]), - development of testis suffers and the germinal epithelium degenerates or may be entirely lacking.

Direct application of heat to the scrotum and testis (Fukui[190], Moore[189]) produces similar effects, the degeneration taking place in shorter time at higher temperatures.

The resistance of the spermatozoa to heat depends to some extent on the stage of development or maturity. Sperms already "ripened" in the epididymis are more resistant to heat than those in the testis (Young[185], Heller[191]).

The degeneration of the testis at body temperature or above is believed to be due to heat lability of testicular proteins (Fuku[190]), or due to the production of hyperaemic condition of the testis associated with oedema, which results into lack of oxygen and accumulation of CO_2 due to vascular stagnation (Moore[189], Barrow[192]).

In contrast to the high temperatures, low temperatures do not appear to be detrimental to the testicular functio s. In rams (Phillips et al[184]) subjected to an exposure of -1 ^{o}C (30.4 ^{o}F) to -3 ^{o}C (26.6 ^{o}F) for 45 minutes, scrotal temperature dropped from 33.3 ^{o}C (92 ^{o}F) to 26.6 ^{o}C (78 ^{o}F) but no detrimental effect on the testes was produced.

The results with the cryptorchid and the experimentally produced cryptorchid animals indicate that the testis functions, normally, at a temperature lower than that of the body. This is effected by the thermoregulatory function of the scrotum.

3. Thermo-regulatory function of the scrotum:

In man and in all the domesticated animals the testes or testicles are a pair of glands lying outside the body cavity in the scrotum which is situated posteriorily between the anus and the urogenital opening. The scrotum consists of a pair of pouch-like sacs communicating with the body cavity by the inguinal canals through which the spermatic cords and vasa deferentia pass. The spermatic cords contain the blood vessels and nerves which supply the testes, and the vasa deferentia are the ducts which convey the testicular secretion to the urethra or common urogenital canal (Marshall (193)).

A peculiar temperature relationship to spermatogenesis exists in mammals with the development of scrotal pouch. The scrotum, from an evolutionary point of view has been a gradual development. In the lowest group of mammals (Monotremata) the testes remain in the body cavity always as they do in birds. In Insectivona (eg. the mole) the testes descend periodically into temporary receptacles and there is no true scrotum.

In many rodents the testes, after descending into the scrotum at the commencement of rut, are withdrawn into the body cavity at the end of the period. In most higher mammals, the testes, after descending into the scrotum during early life (and generally before birth), remain there permanently, but exceptions include whale, elephant, rhinoceros and seal. It is noteworthy that in the ram, after tupping, the organs apparently become smaller and tend to be drawn upwards without, however, passing into the cavity of the abdomen.

This evolutionary change in the position of the testes from the abdominal cavity into the scrotum in the mammals has adapted the testis to a different situation, the conditions of which are markedly different from those of the general abdominal cavity. The testis can no longer function in the primitive position. The great difference between the two situations is one of temperature. The temperature within the testis is considerably lower than that within the abdomen and the temperature of the scrotum in which the testes are lodged must necessarily be lower than that of the abdominal cavity under normal conditions. This was observed by Moore and Quick[194] in rats, guineapigs and rabbits. In every case observed the temperature was $1^{\circ} - 1\frac{1}{2}^{\circ}$ C ($1.8 - 2.7^{\circ}$ F) lower in the scrotum than that in abdominal cavity at the same moment. Moore(180), however, reported a still greater difference - $8^{\circ} - 10^{\circ}$ C ($14.4 - 18^{\circ}$ F) - between scrotal and abdominal temperatures in these animals. In rams (Phillips et al[184]) at room temperatures of 55 to 75° F the scrotal temperature was 11.7° F and the testicular temperature 8.8° F lower than the body temperature (103.6° F). In a study with a Sussex bull Quintan et al[195] found the average scrotal temperature in the sun and shade, at an air temperature range of $65^{\circ} - 91^{\circ}$ F., to be 93.8° F and 92.7° F respectively. The body temperature at this range of air temperature averaged 102.2° F. So the scrotal temperature of the bull in the shed was 9.5° F and in the sun 8.4° F lower than the body temperature.

In a further observation[196] they measured the intra-testicular temperature with a thermo-needle and it was found to remain between 94.5° and 98.2° F at an air temperature range of $59^{\circ} - 100^{\circ}$ F. Artificial displacement of the testis to the close contact of the body of the bull resulted in an increase of testicular temperature by 4.5° F. It is evident from these observations that the scrotal and the testicular temperatures in the farm animals as well as in other mammals are definitely lower than the body temperatures. It also appears that the scrotal temperature is lower than the testicular temperature under normal conditions.

That the temperature of the testes must be maintained constant and lower than the body temperature for the normal spermatogenetic function is evident from the observations already cited where it was seen that the raising of the testicular temperature due to high atmospheric temperatures, by replacing testes in the abdominal cavity or by direct application of heat on the surface of the testes, leads to the degeneration of all seminiferous tubules and germinal epithelium.

There exists a scrotal-testis relationship for maintaining the temperature of the testes. This relationship is one in which the scrotum functions to regulate the environmental temperature for the testis. Moore[180] states that the scrotum is a "temperature regulating mechanism by virtue of its exposed position, thin walls and its response to temperature."

How this thermoregulatory action of the scrotum is effected?

It has been rather common observation that during hot weather the scrota, expecially of bulls and rams, are much more pendulous, whereas on cold days the scrotum is contracted and the testes drawn close to the body. This means that the scrotum does react to the temperature changes. The scrotum maintains the testis at a normal temperature either drawing it away or close to the body depending on whether the weather is hot or cold.

Quintan et al[196] found that, in the bull, the scrotal length averaged 24.2 cm. at low ($50^{o} - 77^{o}$ F) and 29.0 cm. at high ($77^{o} - 104^{o}$ F) air temperatures. They further stated that the length of the scrotum decreased when the animal was exposed to cold in a cooling chamber.

Crew[186] pointed out that this adjustment in the position of the scrotum at different conditions of atmospheric temperature is controlled by the tunica dartos. Lieben[197] gives the following description of the tunica dartos. The tunica dartos is a smooth muscular coat consisting of two layers. The outer layer is very delicate, clings closely to the skin of the scrotum and has fibres arranged in various directions. The inner and by far the stronger layer consists of muscular fibres which for the greater part are turned in the direction from the anus to the root of the penis. In the region of the raphe the tunica dartos turns over on the connective tissue-like dividing wall of the scrotum; thus each testis rests in an individual sac of smooth musculature.

Phillips et al[184] studied the physiology of the tunica dartos of the ram and stated that it functions very much as a thermostat would, furnishing the mechanism by which the thermo-regulatory function of the scrotum is accomplished. Warmth causes a relaxation of the dartos muscle with a consequent removal of the testes from the warmer body temperatures whereas lowering of external temperature results in its contraction, holding the testes close to the body[184][180]. At intermediate temperatures there is constant adjustment, the dartos contracting and relaxing as a result of very small decreases or increases in scrotal temperature. In rams, Phillips et al[184] found that even the isolated dartos reacted quickly to temperature changes, contracting as the temperature decreased and relaxing as it increased. They found it to be most sensitive to changes at temperatures approaching the normal scrotal temperature.

In his work with humans and dogs Lieben[197] found the dartos to react even when far removed spots in the body were stimulated by applications of warm or cold water or ether. The dartos has been found to be innervated by the by the sympathetic and parasympathetic nervous system in such a manner that each scrotal half receives its nerves from the abdominal cord on the same side. Irritation of the sympathetics and the ramus communicas from the first two sacral segments resulted in contraction of the dartos but there were no contractions when nerves from other segments were irritated (197). It appears from this observation that the contraction or relaxation of the dartos, as the case may be, is effected through the reaction of these nerves. The experiments carried out by Phillips and Andrews (198) indicate that in the ram the tunica dartos is dependent upon a testicular hormone for the development and maintenance of its reactivity to temperature changes.

From all this evidence it appears certain that the scrotum is an organ the function of which is to regulate the temperature of the testes and that such regulation is essential for maintenance of continued germ cell differentiation in mammals including the farm animals.

4. Effect of temperature on the fertility of dairy cattle:

The fertility of a dairy bull or a dairy cow is more or less interdependent. The fertility or the reproductive efficiency is ordinarily judged by the number of inseminations required per conception but this number depends as much on the reproductive efficiency of the cow as that of the bull.

The effect of temperature on fertility has been conclusively shown in laboratory animals.

Mills (52) carried out an experiment with while mice under controlled conditions. Keeping other factors e.g. nutrition, light etc. uniform and varying the temperature it was found that, at the "stimulating coolness" (60-70 ^{o}F), the mice were born in large litters of "highly viable young," grew most rapidly and matured earliest. Sexual cycle started early. Immediate conception followed almost every adult mating and the young born were of greater individual size. When the mice were subjected to conditions of high temperature (89 - 92 ^{o}F) and humidity (60 - 70%) growth was greatly retarded and maturity much delayed and this difference in development was maintained throughout the life span. Many apparently healthy females raised in this moist heat never conceived, although mated repeatedly with outside normal males of known high fertility. Both males and females mated just as freely and with as much zest as did those in the cold rooms. It was concluded that the lack of reproductivity of the hot room mice was due to actual suppression of gonadal tissue activity in the sex glands. The author further stated that "there seems to be an optimum environmental temperature for the mouse, probably around 70 ^{o}F., with depression of growth rate and fertility if temperature falls below 65 ^{o}F or rises far above 70 ^{o}F."

The evidences so far obtained with dairy cattle have not been so clear cut as in the case of laboratory animals such as mice etc. The main reasons for this are:- (1) these large animals cannot be so easily handled, (2) the experiment is time-consuming and more expensive; (3) a sufficiently big space is required to handle a fairly large number of animals; (4) the controlling of all necessary conditions in a bigger space with larger animals is difficult. In view of these difficulties no experiment has been made on the effect of temperature on the reproductive capacity of dairy cattle under controlled conditions of temperature. Various general observations made by different workers in different countries, however, indicate the effect of temperature fairly conclusively.

(a) Effect of Season on Semen Quality:

The quality of the semen of a fertile bull is judged from the following properties:- Volume of the ejaculate; motility, concentration, viability on storage, respiration rate and morphology of the spermatozoa; and pH of the semen (Anderson[178]).

Attempt has been made to correlate fertility and semen character. Swanson and Herman[199] found that conception rate was not significantly correlated with pH, P.C. of abnormal spermatozoa or concentration of spermatozoa. He found a highly significant linear correlation between conception rate and viability on storage. This is more of theoretical than of practical interest because such information is not available until after use of semen. Anderson[200] found that the semen of good fertile bulls, on the average, had a high concentration of spermatozoa with good motility and low percentage of abnormal spermatozoa.

Davis and Williams[201] found a highly significant negative correlation between pH and volume, and between pH and motility - the higher the pH value of the semen the lower the motility and the volume. Their findings indicate that the pH change may be of use for evaluating dairy bull semen.

However great variability has been observed in the semen properties among ejaculates of different bulls as well as among those of the same bull (Herman and Swanson[202]) and, as Anderson[203] stated, it is necessary to base the estimate of the quality of a bull's semen on as many criteria as possible.

Few studies have been made of seasonal variations in the semen quality. Weatherby et al[204] reported monthly averages of semen volume, concentration and longevity for five dairy bulls comprising Brown Swiss, Holstein-

-Friesian and Jersey breeds at the New Jersey Agricultural Experimental Station. The data presented by them show that, only from two bulls, semen samples were studied all through the year and that the longevity, concentration and volume varied from month to month. Longevity which was correlated with fertility was generally higher in June and July than in other months but the differences among the months were very slight.

Anderson (200) presented monthly average semen volume and motility observations made on bulls, both dairy and beef, in Kenya. The figures and the data produced indicate a rather distinct seasonal variation with volume and motility low from May to August.

Phillips et al (205) studied the semen characteristics of three beef type and three milking Shorthorn bulls at intervals of two weeks throughout a year. They found that the two breeds responded differently to the influence of season only in storage characteristics. In both breeds the number of abnormal spermatozoa with abnormal heads, necks and middle pieces was highest in summer and lowest in winter. No significant seasonal variations were found in motility, volume and longevity of the sperms though total sperm production was the highest in spring and the lowest in autumn. If the quality of the semen is judged by the number of normal and abnormal spermatozoa then these results agreed, on the whole, with their earlier observations on the dairy bulls in which, from an examination of the results of 1135 matings during the period 1935 - 42, they found that the semen quality decreased during the summer.

Contrary to these observations Anderson (206) reported that good quality semen coincided with high temperatures and bad quality with low temperatures in Kenya. He stated that certain climatic conditions which include temperature and amount of sunshine appeared to affect bull semen in Kenya. The maximum temperatures (75^{o} to 80^{o} F) experienced during the period of observations (July 1939 - December 1941) were not considered to be particularly high and within this range a high temperature was associated with better semen and vice versa. It has been stated that, in general, mating desire and semen quality were highest during January - February and September - October, when temperatures and hours of sunshine were highest and humidity lowest. In April - August the temperatures were comparatively low and the relative humidity was the highest. The semen produced during this period was stated to be poorest. In conclusion the author stated "under Kenya conditions there would appear to be a basic seasonal rhythm in bull semen, an increase in semen characteristics being associated with warmer climatic conditions and vice versa. A lengthy period of high temperature may have an adverse effect."

In this observation the temperature variation was very small and the high humidity accompanying the relatively low temperatures might offset the temperature effect. However, the data show that there was considerable variation between years, between bulls and between farms. Hence no conclusion can be drawn from this observation.

Erb et al (207) studied semen samples produced by four young and healthy Holstein, Jersey and Syrshire bulls over a period of one year at the Purdue University Agricultural Station. The animals were maintained under the same system of management and on a uniform grain ration without any access to pasture throughout the year.

The data presented show that the average semen volume, average initial motility and average longevity of sperms were the least in July, August and September (summer) and the average number of abnormal spermatozoa was the highest

(25 p. c.) during these months. The average concentration of spermatozoa and total sperm per ejaculate was maximum during April, May and June (spring).

The data was summarised and statistically analysed for season variations in all the characteristics of the semen except pH which showed little change in either the same or between different bulls. The analysis shows that, considering all the characteristics, semen produced during the spring was of the superior quality and that produced during the summer was the poorest. The semen produced in autumn and winter did not vary significantly from the mean.

Since the management and plane of nutrition were similar throughout the experimental period it can be concluded that the changes observed in the semen quality were the results of those factors which characterise the seasons - temperature, light, relative humidity and other general atmospheric factors.

The authors believed that temperature changes were greatly responsible for the seasonal differences in the semen quality. They stated that, during the summer months when the inferior quality semen was produced, total motility, survival, concentration, initial motility and volume were least at the time the maximum temperatures occurred. They further stated that "the rapid changes in temperature either up or down seemed to be reflected in the semen quality."

In the dairy bulls of the Missouri University herd Swanson and Herman (208) did not find any significant seasonal effect on the semen quality. In this experiment thirteen purebred bulls, Holstein-Friesians, Jerseys and Guernseys were used. They varied in age from $1\frac{1}{2}$ to 13 years, the average being 6 years. Uniform ration consisting of legume hay and grain mixture was supplied all the year round.

The data and the curves presented did not indicate any definite seasonal variations of some semen characteristics but others seemed to vary with the seasons. Volume appeared to be greater in spring months (April to July). Initial motility and viability were significantly lower in winter months (January to March) then in spring and summer (July to September) and the pH of the semen was significantly lower in the summer (6.42) than in the fall (6.82) and the winter (6.59).

The concentration and percentage of abnormal spermatozoa were not significantly different during the seasons. It appears from this study that the semen quality was poor in winter as compared with the spring and summer months and the low temperatures during the winter appear to have a deleterious effect on the semen quality.

However the authors stated that these changes were confined to old bulls (over four years old) and the semen from young bulls was as good in motility and viability in December and January as it was in June and July. The aged bulls seemed to suffer more from cold weather than the younger bulls and showed less sexual desire or vigour in winter. The general lowered physical vigour possibly was reflected in decreased vitality of their spermatozoa. Since the majority of the bulls were aged bulls the changes in the average semen quality in this study was probably due to the poor physical conditions of the bulls during winter and not due to the direct seasonal effect on the semen characteristics. Considering these points the authors concluded "it does not seem that spermatogenesis in the dairy bull is significantly affected by season."

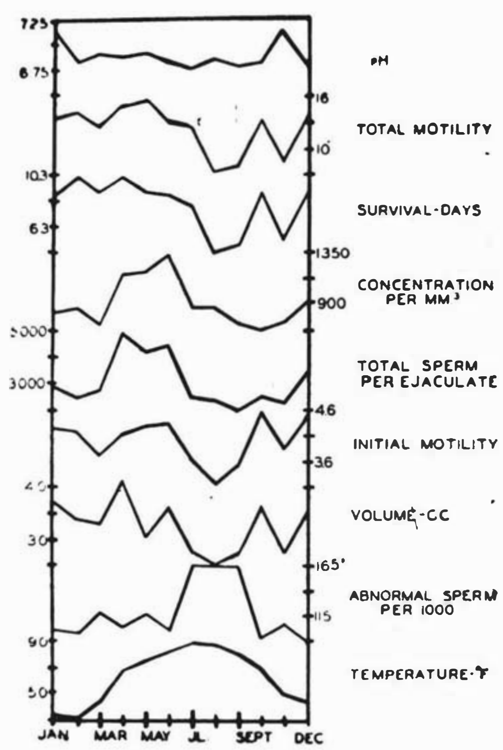


FIG. 12.

Monthly variations in the semen quality of 4 bulls. (From Erb et al[207]).

However, The detrimental effect of sudden changes in weather, either hot or cold on the semen quality was observed by both Erb et al/and Swanson and Herman. Herman and Swanson[209] found, in one out of ten bulls studied, that the quality of the semen decreased, initial motility was poor and longevity lessened under the conditions of cold icy weather. Apparently the literature in general is not in complete agreement on the effect of season on the semen quality of bulls. Moreover in most of these experiments feeding and management conditions have not been mentioned and the temperatures during the periods of observation have not been recorded and, therefore, no definite conclusion regarding the effect of temperature on semen quality can be arrived at. However the reasonable expectation in this respect appears to be borne out by Erb et al's[207] observation which was made under the uniform conditions of feeding and management and on fully active bulls of good fertility.

That the season as represented by temperature has a definite effect on the semen quality is evident from the figure presented by them. The figure (No. 12) clearly shows that the average total number of abnormal spermatozoa increased, and total motility, longevity, concentration, survival, initial motility and volume, total sperm per ejaculate i. e. all the characteristics which can be related with fertility, were the least when the maximum temperatures occurred during the months of July, August and September.

(b) Effect of higher body temperature on semen quality:

It has been evident from Erb et al's[207] observation that high environmental temperatures are detrimental to the semen quality of dairy bulls. This is supported by the findings of Lagerlof[210] who raised the scrotal temperature of a bull by means of scrotal insulation. He found that the insulation resulted in changes in the germinal epithelium accompanied with poor semen quality. The longer the period of insulation the more marked were the changes in the number of normal spermatozoa and the greater was the increase in abnormal types. The increase in the number of abnormal spermatozoa started about eleven days after the beginning of insulation, the insulation being carried out on alternate days. Motility was the first to be affected (at about 5 to 9 days). There was an increase in "unripe" spermatozoa (i.e. spermatozoa with protoplasmic drops on their neck) about the same period as the increase in abnormal types.

Anderson (178) noted a decrease in semen quality in the bull after anaplasmosis and foot and mouth disease. He observed that this was probably due to increased body temperature affecting spermatogenesis rather than to the actual disease processes. In one bull, just after the recovery from foot and mouth disease the concentration of spermatozoa was normal, but the motility was poor (20 p.c.) and the pH was rather high; nine weeks later the motility was good (80 p.c.) and the pH lower (6.60), since when the bull maintained the production of good sperms. Lagerlof (211) reported that the inflammation of one testicle might disturb spermatogenesis in the other as well, through the rise in scrotal temperature and the disturbance in the heat regulating function of the scrotum. The infected testicle swelled up greatly and could not move up and down in the scrotum in the normal manner. The bull showed fever and high temperature The high temperature remained for sometime and after about a fortnight spermatozoa were very few or absent. He stated that if the affected testicle is removed immediately at the beginning of the infection it is possible to save the sound testicle.

It appears certain from these observations that

that higher atmospheric temperatures in a similar way, by causing the body and scrotal temperatures of the dairy bulls to rise, will bring about spermatogenetic degeneration.

(c) Effect of temperature on conception rate and fertility:

From the foregoing findings that poor quality semen is produced under the higher summer temperatures it can be expected that the number of services required per conception during the summer, depending upon the severity of temperature of course, will be greater than that in the spring and the winter. This was found to be the case by Morgan and Davis (212). These authors studied 38 years' breeding data of the university of Nebraska dairy herd. Considering bulls of all ages mated to 2,090 cows, they found that 2.21 services were required per conception over this period. It was found that slightly more services per cow were required from May to October than from November to April, with the lowest number required in December and the highest in September.

Similar results were obtained by Miller and Graves (213) in the herd of dairy cattle maintained at the U.S.D.A. Animal Husbandry Experimental Farm, Beltsville. The herd consisted of purebred Holsteins and Jerseys and grades of the two breeds. The authors found that during the months of July, August and September more services were required per conception than in other months of the year.

Phillips et al (205) who, in their studies on the seasonal variations in semen of bulls, noted the semen quality to be poor during the summer with greater number of abnormal spermatozoa, found, in an examination of the results of 1135 matings over eight years, that the decrease in semen quality resulted in decreased breeding efficiency. The highest percentage of fertile matings occurred in April (59.6%) and the lowest in August (40.8%). This shows that the spring temperatures, ignoring the effect of feeding etc. which have not been mentioned, are optimum for the fertility of dairy animals and that both the higher and lower temperatures, although the latter comparatively less severely, affect the breeding efficiency. This is in agreement with Erb et al (207), Swanson and Herman (208) who found the better quality of semen to be produced in spring.

Hammond (214) stated that, although cows will breed at any time of the year, yet in England there is an optimum time - during the summer months (May - July) - when the reproductive force is at its maximum and conversely during the cold weather of the winter months (November - January) the reproductive powers are at a minimum. He also recognised that there is an optimum temperature for the reproductive efficiency of the cows. This seems quite likely considering the fact that the summer temperatures in England are not excessively high, rather mild, and the winter temperatures are exceedingly low, specially during severely cold weather.

Erb et al (215) studied the breeding efficiency in the Purdue University dairy herd for the twenty year period and found considerable seasonal variation. The study included 1,440 services resulting in 922 conceptions. They found that the highest average efficiency (74.3%) for the year occurred in the month of May and the lowest average efficiency (58.2%) in the month of August.

This observation is in complete agreement with Phillips et al's (205). The feed conditions and management and temperatures have not been mentioned and the authors have not attributed this great difference in breeding efficiency between seasons to any factor or factors. But it can be reasonably said that the temperature was a main factor, if not the s ngle factor, for this difference.

That the atmospheric temperature, specially high atmospheric temperature greatly affect the breeding efficiency of dairy cattle is borne out by the observations of Dawson (216) made on twenty proved (aged) sires used at several experimental stations of the United States Department of Agriculture, except Beltsville. The sires included eight Jerseys, two Guernseys and ten Holsteins and they varied from five to ten years of age at the time. The bulls were fed and managed well at all the Stations. The feed consisted of good quality legume hay and grain mixture; silage was fed sparingly.

The females in the various herds where the bulls were in service were fed and managed under desirable conditions. All cows on official test were given good legume hay and silage, and a grain mixture. The herds were subjected periodically to tests for Bang's disease and it was believed that breeding trouble with females was no more serious in these herds than in the average breeding herd.

Considering the service records of all the twenty bulls used at all Stations except Beltsville, the authors found that there was a tendency for the fertility to be somewhat higher during the months of February, April, July and October, when the fertility based on number of services to fertile cows, averaged 42.9%. The low trends were found in June, September and November (figure 13) when the average fertility was 36.5%. So the seasonal effect was not pronounced and it could not be expected because of the wide range of climatic conditions which prevailed at these stations.

The author subsequently divided the Stations into two groups - (a) the southern group; and (b) the western and northern group - according to climatic conditions, and studied the service records of the two groups seperately.

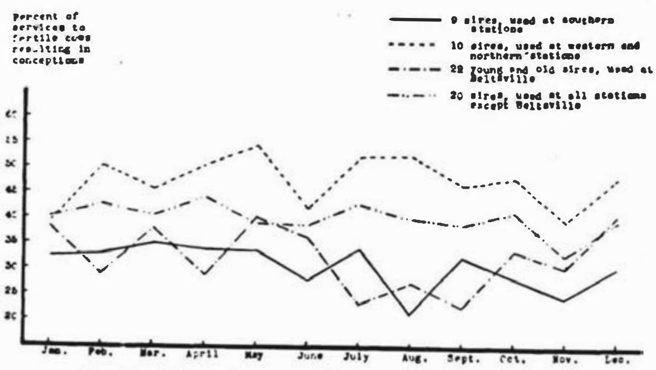


FIG. 13.

Effect of season of the year on fertility of sires. (From Dawson, J. R. (216)).

Of the nineteen of the sires nine were included in the southern group and ten in the western and northern group.

As it appears from the figure (No. 13) the sires used at the southern Stations had decidedly lower average fertility (36%) than those used at the western and northern Stations (49%). The author attributed these differences to higher temperatures and humidity at the southern Stations. At the western and norther Stations during the summer the temperature rose quite high but as a rule dropped sharply at night. In the figure has been included a curve drawn from the observations of Miller and Graves (217) who, in a study of 22 young and old bulls used only at the Beltsville Station over a period of four years and including 1,539 services of fertile cows, found the lowest fertility (23%) in July - September, after which the fertility increased during the fall and winter months (see figure). Miller and Graves suggested that the hot weather during the summer influenced the functioning of the genital organs adversely and that genital efficiency increased with the advent of autumn. This is in agreement with the previously cited observations on the effect of temperature on the genital function in sheep and the laboratory animals. The figure further shows that the curve for the southern groups follows that of Miller and Graves's Beltsville group more closely than does the curve of western and northern group. It has been stated that this was so because the temperature and humidity conditions at Beltsville were more similar to the southern group of Stations.

That the higher environmental temperature affects the fertility of the dairy cattle not only through the bull but also through the cow has been noted by Bonsma (44) in South Africa. He stated that if bulls which are kept in the shade serve cows which have been out in the sun, the high body temperature of the latter will have a deleterious effect upon the vitality of the spermatozoa and the cows will consequently not conceive and "this apparently, is one of the reasons why so few cows calve during July, August and September on farms where the bulls run with the cows during the summer."

It has not been studied whether atmospheric temperature has any effect on the functions of the ovary of a cow such as production and maturation of ova or the heat cycle of the cow, although it has been noted that under natural conditions the cows have seasonal breeding system. Of the ewes Rhoad (218) reported that the major breeds come in heat and breed during October and November, when the temperatures are considerably below the average of summer months.

However, it has been observed that, on the whole, the reproductive efficiency of the cows are greatly affected by atmospheric temperatures, specially higher temperatures. Villegas (219) reported on the Holstein-Friesian cows which were imported in Singapore (where the temperatures are usually very high) and of which one lot was kept in air-conditioned barn at 70 °F and the other lot in the freely ventilated barn. In the air-conditioned barn 58% of the cows conceived within five months as compared with only 25% in the ventilated barn.

<u>(d) Differences between Bos Indicus and Bos Taurus cattle</u>:

Few workers have noted that the Zebus and the European cattle imported in the tropical countries are affected differently by environmental temperatures so far as fertility is concerned. The purebred European dairy cows imported in the tropical countries have been found to have longer service periods than the Zebus. Harrison (220) in Trinidad, studied the service periods of purebred Zebus and purebred Friesians and also the influence of Zebu blood on the service periods in the Zebu-Friesian crosses in Trinidad. He obtained the following results:

TABLE 20.

Grade	Av. Service Periods (days)
Pure Friesian	236.1
7/8 "	176.4
3/4 "	164.1
1/2 "	131.5
3/8 "	114.4
Pure Zebu	100.1

It appears from the table that in the tropical countries the higher the proportion of Friesian blood in a dairy ahimal, the longer the service period. This agrees with the observation of Villegas that the greater percentage of the imported Driesians in Singapore conceived within five months when kept in a air-conditioned barn than when kept in a ventilated barn.

In Hong Kong where the high atmospheric temperatures with high humidity occur from March to October, Watson (221) similarly found that the imported cattle of European breeds (Holstein, Ayrshire, Jersey) would have a rest period of at least six months after parturition whereas the native cattle would usually conceive within four months of calving. Harrison obtained similar results with regard to the service records. These are presented in the following table. The average service records have been calculated by taking the average service record of the purebred Zebu as 100:

TABLE 21.

Grade	Relative no. of services
Purebred Friesian	382
7/8 "	362
3/4 "	211
1/2 "	190
1/4 "	109
Pure Zebu	100

These figures show that the Friesians in the tropics required about 3.8 times the number of services per conception as compared with the Zebus and that with the increase of Friesian blood in the animal the number of services required per conception increased.

Similarly Anderson (222) reported that in Kenya an average of 1.3 services was required per conception in the Zebu herds whereas in the grade herds (breeds not mentioned) the number of services required per conception varied from 1.5 to 9.8 with an average of 3.6. In these observations this variation in the number of services per conception is probably a measure of fertility of both the cow and the bull rather than the cow or the bull alone.

Considerable differences in the fertility of Zebu bulls and bulls of imported European breeds in the tropics have also been recorded.

Anderson (222) stated that the fertility of bulls in Kenya, mainly purebred bulls of different breeds (breeds not mentioned), estimated from cows with good breeding records, had been found to vary from 10.2 to 62.8% in different grade herds, with an average of 27.6%. Whereas in two herds of Zebu cattle the average fertility of the bulls was 71.4% and 83.3% respectively.

Daubney (223) on the other hand did not find any evidence that atmospheric temperature conditions in Kenya adversely affect reproductive functions in purebred and grade Surppean bulls to any appresiable extent. He has stated that almost the whole of the areas in Kenya where stock-raising is already established enjoys an annual temperature below 65 °F and he regarded that this temperature is eminently suited to the raising of cattle of European breeds. However, he admitted that in some areas and in certain seasons temperature conditions may be more adverse.

It appears that the cause of this difference in observations made by Anderson and Daubney is due to the variable temperature conditions, from season to season and from area to area. However there seems to be no doubt that the more adverse temperature conditions will affect the fertility of the cattle of European breeds in Kenya.

In Kenya it has been noted by Anderson (178) that apart from the actual temperature to which the animal is exposed, the period of exposure has a greater effect in grade than in Zebu cattle. He stated that the intermittent nature of the periods of the high and the low daily minimum temperatures experienced in the highlands of Kenya probably offset, to a great extent, any adverse effect that high temperature might have on male reproduction.

The degenerating effects of higher atmospheric temperatures on the exotic (imported) beef breeds have been observed by Bonsma et al (44) in South Africa. They found that many bulls belonging to the exotic breeds (Aberdeen Angus, Shorthorn and Hereford) became temporarily sterile during the hot months. They attributed this to the increase in scrotal, testicular and body temperatures due to high atmospheric temperatures. During the hot months with atmospheric temperatures of 90 ^{o}F the body temperatures of the bulls of these breeds rose to 106 ^{o}F and the scrotal temperature to 115 ^{o}F. This abnormally high scrotal and testicular temperatures most probably resulted, as has been shown in rams and the laboratory animals, in the testicular degeneration.

The authors further noted that the scrotal skins of these bulls was very thin (0.15 to 0.2 cms.) and that this caused the temperature of the testes, which are in direct contact with the skin, to rise much higher than even the body temperature did. The fertility of the Africaner bulls, on the other hand, were practically unaffected by the higher atmospheric temperatures. They stated that this was probably due to the fact that these animals were equipped with efficient mechanism for regulating body and testicular temperatures. They noted that in the Africaner bulls the skin of the scrotum is twice as thick (0.4 cms.) as that of the exotic animals and that when the atmospheric temperature rises high the scrotum of the Africaner bull is retracted so that the skin becomes puckered and consequently a poor conductor of heat. In addition the testicles are retracted against the perivisceral cavity so that their temperature does not rise above that of the body temperature.

It appears certain therefore, that overheating of the testicles resulted in the sterility of the bulls belonging to the exotic breeds in South Africa.

In conclusion, the authors stated that in the case of Africaner cattle, "the seasonal fluctuations in conception are, therefore, due to seasonal fluctuations in the sexual activity of the females rather than to lowered fertility of the bulls." In the case of the exotic beef breeds, however, the cows also showed seasonal fluctuations in sexual activity, but the seasonal fluctuations in conceptio reflected "real changes in the fertility of the bulls."

It can be concluded from all this evidence that the environmental temperature has a profound influence upon the reproductive efficiency of cattle. Extremes of temperature, both high and low, greatly affect the semen quality of bulls. High temperatures cause the body and scrotal temperature of the bulls to rise, the prolonged exposure leading to spermatogenetic degeneration. Further the increased body temperature of a cow at high atmospheric temperature will have a deleterious effect upon the spermatozoa deposited in her genetalia. The net result is lowered breeding efficiency. Zebus are more fertile than the European cattle under tropical temperature conditions.

(5) Efficiency of heat dissipation and fertility:

From what has been said before it appears that the lowered fertility of bulls due to higher atmospheric temperatures is mainly due to the increase in the temperature of the testes which function normally at a temperature below the body temperature. Thermo-regulatory action of the scrotum helps to maintain the testicular temperature at normal either moving the testes away or close to the body. This mechanism becomes useless when the body and scrotal temperatures both rise under the high environmental temperature conditions; and as a result the temperature of the testes rises. Rise in the scrotal and body temperatures, on the other hand, are dependent on the efficiency of heat dissipation. The scrotal and body temperatures of an animal which possesses an efficient heat regulating mechanism is unaffected by higher environmental temperatures, within limit of course, whereas in the animals with less efficient mechanism the scrotal and body temperatures both rise rapidly.

That the efficiency of surplus heat dissipation is important for male reproduction has been noted by Phillips et al (184) in rams. They made observations on two rams in which the testes under the handicap of high condition (fat) and a covering of wool, were unable to continue normal spermatogenesis. After removal of the fleece, with some coincident lowering in condition, the testes regained normal spermatogenetic function. The situation with these two rams parallels that of the rams which were subjected to scrotal insulation by others.

In all these cases the dissipation of the surplus heat from the body and the scrotum was made difficult and as a result spermatogenetic degeneration took place.

The differences in fertility found by Harrison (220), Anderson (178)(222), Villegas (219) and Bonsma (44) between the Zebus and European cattle imported in the tropics can be associated with the efficiency of heat regulation. The Zebus have been found to be much more efficient (cf. body temperature, respiration and pulse rate) than the European cattle in disposing of surplus heat and their body temperature, compared to the European cattle, is only slightly affected by higher atmospheric temperatures of the tropics. Apart from this the Zebu bulls most probably posses, as noted by Bonsma (40) in Africaner, thicker scrotal skin and can perform better scrotal adjustment by retraction and puckering of the scrotum, than the bulls of the European breeds. Hence the temperature of the testes of the Zebu bulls at higher atmospheric temperatures is maintained at more or less normal level which is necessary for normal functioning of the testes and so their fertility is either unaffected or only slightly affected by higher tropical temperatures. On the other hand the fertility of European bulls which are much less efficient in elimination of surplus heat is seriously affected. Therefore, efficiency in heat dissipation at high environmental temperatures is important in the fertility of dairy cattle under tropical conditions.

D. INFLUENCE OF TEMPERATURE ON PRODUCTION OF DAIRY COWS:

Environmental temperatures may affect the production of a dairy cow through direct and indirect influences. The indirect influences are exerted through its effects on the constitution of the animal and the availability or the abundance of feed. Although many other climatic factors act in collaboration with temperature - and in many cases it is impossible to segregate the effect of temperature from the effect of other climatic factors - temperature has been found to be a factor in directly affecting the day to day production of the dairy cows (both the production of milk and butterfat). It is also a general observation that humidity along with temperature plays an important part in this respect but enough evidence is not available supporting this observation.

Various workers in different countries have carried out experiments or made observations in order to study the effect of environmental temperature with its seasonal and diurnal changes and also when increased or decreased artificially upon the production of the dairy cows.

It is generally believed that the dairy cows unlike the steers are least able to withstand exposure to cold temperatures. Henry and Morrison (224) stated that the steer, gorged with feed and every day adding to the heat--holding layer of fat just beneath the skin, prefers the yard or open shed to the stable in winter. The cow of dairy type and temperament stands in strong contrast, her system being severely taxed through the annual drain of maternity and the daily loss of milk. "She is spare instead of being protected by fat and consequently has more body surface to radiate heat than the steer per 100 lbs. L.W. Furthermore her hide is usually thinner and her coat more scanty than in the case of the beef steer. She should, therefore, be comfortably housed in a well-ventilated, well-lighted stable having a temperature not below 40 to 50 ^{o}F in winter." Eckles[225], on the other hand, stated that "dairy cattle, when well fed, are not sensitive to low temperature as is sometimes assumed," but the cows and young stock should not be unduly exposed to severe weather, while cold rains and snow storms are specially to be avoided.

Jordan[118], as early as 1905 reported that dairy cows produced 55-85% more heat than their maintenance needs and Armsby[119], therefore, saw no reason why a cow might not be subjected to low temperatures without causing any extra heat production for maintenance of body temperature.

Animals wintering outdoors develop in response to cold weather, highly insulating coats of fur and feathers and subcutaneous fat. Further by driving the blood from the body surface at declining temperature the blood is kept from cooling and the skin becomes highly non-conductive to heat. Moreover farm animals consume large quantities of feed associated with high heat production due to feeding. In ruminants, particularly in cattle, with their diets containing large amount of roughage and with the rumen microflora converting even urea to protein and fermenting the ingested feed stuffs with high heat production, the extra heat increment due to feeding is very great. Brody[120] stated that this heat increment in farm animals is about 20% of the gross energy of the customary balanced mixed rations consumed, and that heat production in dairy cattle under normal feed conditions is about 50% above that in the fasting condition. This extra heat due to feeding can be utilized advantageously by the animal for maintaining body temperature. Brody stated that this partly explains why ruminants, on a poor hay diet can be easily wintered in the cold western states of U.S.A. where the temperature is often as low as -40 ^{o}F.

It appears, therefore, rather certain that the dairy cows do not decrease in their efficiency, nor arethey uncomfortable under the conditions of cold weather, provided they are protected from severe changes in weather such as snow, rains and storms. It is true that under basal metabolism conditions the critical temperature of farm animals is 60 to 70 ^{o}F (15-21 ^{o}C). Such values have been reported for domestic fowls, pigs and steers (Brody [27][120]). These critical values may be interesting theoretically and for research purposes but they are probably without significance under the conditions of normal management systems because the animals on the farm are not on a basal metabolism level and the surplus heat produced by the animals due to the effect of feeding roughages etc. is huge and can be utilized for the maintenance of body temperature etc. in cold weather. However under high environmental temperature conditions this surplus heat production is a serious burden to the dairy animal and the disposal of it is a difficult problem (cf. heat regulating mechanism). There appears, therefore, to be hardly any critical temperature lower down on the scale below which heat production should be increased for maintaining body temperature but there is definitely a high critical temperature above which the normal physiological processes such as body temperature, respiration rate and metabolic functionsetc. are affected. Considering these it appears that at low temperatures the production of the well fed dairy cows would not be affected but at higher temperatures production will be seriously affected because of the physiological upset of the cows. The optimum range of temperature for production, therefore, appears to be a large one starting from the upper critical temperature down the scale to a sufficiently low temperature. This is, however, only an expectation and it will be interesting to see how far it agrees with the results of the actual observations.

Effect of temperature on milk production:

Buckley[226] at Maryland in comparing open stables with closed stables found that "the effects of extremely low temperatures are practically negative in reducing the flow of milk." Woodward et al[227] also compared the open shed with the closed barn for milking cows and reported that cows "consumed somewhat more feed and produced slightly more milk when kept in the open shed than when kept in the closed barn." Kelley and Rupel[228] studied the relation of stable environment to milk production and found that under Wisconsin conditions the optimum stable temperature for dairy cows appeared to be about 50 ^{o}F and that cows running in a pen withstand low temperatures better than stanchioned cows. Regan and Richardson[63] obtained similar results with cows housed in air-conditioned room. They demonstrated that heavy milking cows withstand cold temperatures better than warm temperatures. On the other hand Davis[229] compared an open shed with a barn for milking cows in Pennsylvania and concluded that drops in atmospheric temperature decreased the milk yield for both groups and that the cows in the open shed consumed more roughage than the cows in the barn. The details of these observations were not obtainable. Speir[230] carried out experiments at Newton, England on the production of milk in winter under free versus restricted ventilation. He observed that free ventilation is an important factor in the production of milk in mid-winter and that this is desirable for the production of wholesome milk just as for the health of the animals. He further stated that there was no difficulty in producing milk in freely ventilated byres in the coldest weather in England and that "rather more milk has been produced under conditions of free ventilation than where ventilation was restricted."

Dice[125] working at North Dakota Agricultural College Farm has shown that the dairy cow withstands long periods of exposure to temperatures as low as 0 ^{o}F with little loss either in production or in the efficiency of food utilization. Working with cows kept in an open shed versus cows kept in a dairy barn he showed that, for three two-month periods in different years, the cows kept in open shed were somewhat more persistent producers than similar groups housed in the dairy barn and that milch cows can stand low temperatures provided they have access to shelter that is dry and free from drafts. Dice[53] conducted further experiments on the influence of stable temperature on the production of dairy cows. The preliminary work on the project was done to demonstrate the effect of turning milking cows out in the yard in the morning cold weather and leaving them out all day. The production and persistency of production of a group of five cows were compared with that of a similar group kept in the barn and turned out for exercise for a few hours on nice days. All of the cows were kept in the barn during the night. At the end of two months, November-December it was found that the out-of-door cows maintained their production on a par with those kept in the barn. The mean temperature for November was 22 ^{o}F., for December 9 ^{o}F., with the minimum going below zero several times. The health of the yard cows was not affected by the exposure to cold. The barn cows gained 184 pounds in live weight and the yard cows gained 207 pounds during the two months period.

To check these results other groups of cows were turned out night and day during February-March and again during November-December with access to an open shed. The production of these groups was compared with that of similar groups housed in the dairy barn. The mean temperatures for February and March were 23.0 ^{o}F and 27.0 ^{o}F respectively and for November and December were 30.4 °F and 19.8 °F. The following table gives the result of the two comparisons.

TABLE 22.

Average daily milk production by groups (converted to 4% milk.

Period	No. of cows		In Barn: Daily prodn. of 4% milk		In Shed: Daily prodn. of 4% milk	
	Barn	Shed	1st month	2nd month	1st mth.	2nd mth
Feb-March	3	3	88.74	81.86	98.27	91.41
Nov-Dec.	4	4	115.48	103.27	116.12	101.44
Total	7	7	204.22	185.13	214.39	192.85
Lbs. drop in daily production				19.09		21.54
% drop in daily production				9.35		10.05
lbs. daily produced per cow			29.17	26.45	30.63	27.55

The data seem to indicate that the cows housed in cold quarters produced practically as well as those kept in the standard dairy barn. The percentage drop in production was slightly higher in the shed cows than in the barn cows but the difference is not significant.

The experiment was further continued during the next two seasons and the method was somewhat changed. One group was kept in the dairy barn while the other group was in the shed and then the next month the two groups were reversed. This plan served to overcome any of the inevitable differences that existed in the two groups. The producing ability, stage of lactation, size and breed of the cows were considered in making up groups. The cows were fed hay, silage and grain according to their needs.

The summary of the results obtained are given in the following table.

TABLE 23.

Same cows in barn and shed - alternate months	1st Season		2nd Season	
	Barn cows	Shed cows	Barn cows	Shedcows
Lbs. 4% milk produced	16,358	16,305	27,910	27,887
Mean humidity	83.50	73.40	82.92	67.23
Mean temp. °F	52.20	25.95	53.90	34.96
Lbs. gain or loss in weight.	+363	+440	-134	+1199

The table shows that although the temperature in the shed was very much lower than that in the barn, the production of F.C.M. (fat corrected milk) was practically the same in the barn and the shed. It appears that the temperatures below 54 °F and as low as or lower than freezing point did not make any appreciable difference in the production So far as the health of the animals was concerne the shed animals as is evidenced by the weight gains did remarkably better than the barn animals.

The experiments carried out by Dice demonstrate that the idea that dairy cows receiving an adequate ration need to be kept in warm barn to be comfortable is unsound. The author in his concluding remarks stated that, provided the dairy cows receive an adequate ration, have shelter from the wind, snow or rain, andhave a dry place to bed down, "they can withstand exposure to cold temperature and they will produce practically the same in a cold stable as they will do in a stable where the temperature is about 50 °F." He further stated that milk cows on full feed, when housed in a cold stable produce sufficient surplus heat to maintain body temperature without using nutrients specially for that purpose (cf. metabolism).

Woodward et al (231) in Washington studied the influence of season on milk production and found that, apart from feed supply, temperature is an important cause of fluctuation of milk yield from season to season. They obtained 15,492 D.H.I.A. lactation records from 12 states and compared the monthly yields with those shown by 101 lactations from Beltsville herd, where feed conditions were kept uniform by constant indoor feeding of the cows. At Beltsville, under the controlled conditions of feed supply, the maximum yield of milk occurred in spring(May) and the minimum yield in July when it was the hottest. In the 12 states the minimum yield occurred from October to December. The author stated that the food supply had much to do normally with the seasonal fluctuations in milk yield in the states and that on a uniform level of feeding the high temperatures were found to be the cause of the minimum yield in July and comparatively low temperature in May coincided with the maximum yield.

Full details of the experiment were not available and whether the May temperature was the lowest in the year and, if not, how production was affected during the coldest months cannot be said. However the adverse effect of high summer temperatures is evident.

Campbell[(232)(233)(234)] in his study on the effect of night on milk production at the University of Reading stated that temperature was the main cause of the difference between the morning milk yield and night milk yield. It is usually believed that the longer interval between night milking and morning milking is the main cause of the difference in the milk yield but Campbell found it to be otherwise. He stated that these may be differences of over 35 ^{o}F between day and night temperatures outside in the spring and summer months in southern England. He made observations with five cows and a heifer and presented data to show the proportions between morning and evening yields of milk and fat, and fat%, in the case of individual cows milked alternatively at 6 a.m. and 9 p.m. and again at 6.30 a.m. and 3.30 p.m. In each case the intervals between milkings were 15 and 9 hours.

He found that when the 15 hour interval was between night and morning milkings, a bigger proportion of milk was produced at the morning milking than was produced at night when the same interval was between morning and night milkings. In conclusion he said that the comparatively lower temperature during the night might tend to higher milk production of lower fat content in the morning.

Harlass (235) in an experiment with Black Pied Lowland cows attempted to ascertain the most satisfactory range (optimum range) of temperature for production. Eighteen cows at the height of lactation were divided into three groups of six animals according to age, performance and pedigree. Group I was allowed to graze day and night, while Group II and III were housed at night and by day respectively during the first period of the experiment. Each group was then subjected to alternative treatment during the two subsequent periods. During the first period (June to July) the "lowest" average environmental temperatures were found to correspond to "the lowest" milk yield (23.2 kg. Group I), the "highest" average temperatures to the "intermediate" yield (24.2 kg. Group II), and the "medium" temperature to the "highest" yield (25 kg. Group III). The opposite was true of fat content, Group I giving the highest daily yield (744 g.) followed by Group II (722 g.) and Group III (698 g.). In the 2nd period (July to August), it has been stated, continuous grazing had an unfavourable effect on milk fat mainly due to "high maximum temperatures", and in the 3rd period (August to September) housing by day was found to lower milk yield, since high maximum temperatures no longer occurred, while housing by night increased both milk yield and fat content. It is remarked by the author that "Milch cows should, therefore, be protected from extremes of temperatures (maximum in summer and minimum in early summer or autumn)." In this experiment of Harlass atmospheric temperatures have not been mentioned and the "highest", "lowest" and "intermediate" temperatures are vague terms. It has been stated that Group I was subjected to 24 hours' grazing and consequently to the "lowest" environmental temperatures. It has not been mentioned whether any shelter was provided to protect the animals from sudden weather changes which alone, apart from low temperature, might have affected production. Moreover the yields of milk and butter-fat are not sufficiently different to show any marked effect of temperature and this difference in production might be due to group differences. The best way that the experiment could be done was (1) firstly to check the production of the animals individually as well as a group under uniform conditions of management and then (2) to subject the three groups of animals to the three treatments seeing that all the animals were adequately fed according to live weight and production and that other conditions excepting the variations of environmental temperatures were similar as far as possible.

In the second period of this observation the high maximum temperatures to which the cows were exposed during continuous day and night grazing had an unfavourable effect on the milk fat content. The effect of temperature on the butter-fat percentage will be dealt with later. Continuing the experiment during winter (December - February) Harlass kept six Black Pied Lowland cows in a heated byre at six different temperatures. It has been stated that the highest milk yields were usually found at medium byre temperatures - 16 °C (61 °F), 15 °C (59 °F) and 10 °C (50 °F); high temperatures - 24 °C (75 °F) and 20 °C (68 °F), and low temperatures - 6 °C (43 °F) - lowered milk yield. It has been stated that the same was true of total fat, but low byre temperatures increased the fat percentage. It was observed that "the most satisfactory temperatures for both milk and fat performance, therefore, ranged between 10 °C (50 °F) and 16 °C (61 °F)."

According to Harlass the optimum range of environmental temperature for maximum production of milk lay between 50 °F and 60 °F and temperatures as low as 43 °F gave the lowest yield. This appears to be contradictory to the results obtained by Dice who found that the temperatures between 23° and 53 °F did not affect the milk yield appreciably. The number of animals used by Harlass - one for each treatment - was very small and whether the animals were reversed has not been mentioned. Even breed difference might be a responsible factor for this difference in observation.

Witzel and Heizer (236), University of Wisconsin, Madison, studied the effect of temperature on production. They compared during two winters, two herds, each of 17 Holstein-friesians, one kept in an insulated stall barn and the other in an open pen barn. Mean outside temperatures were 40.8° and 35.8 °F respectively during the two periods and in the stall barn the temperature was 45-55 °F. It was stated that in the first year of the experiment milk production in neither barn varied with changes of temperature but in the cold open barn it averaged 7.4% less than in the warm insulated barn. During the second year when the cows were distributed at random, the production of F.C.M. was the same in the warm and the cold barn.

Sinha and Minnet (237) carried out observations at the Imperial Veterinary Research Institute, India on fifteen milking buffaloes in order to ascertain whether any relationship exists between milk yield and cooling of the body by daily wetting of the body surface. Fifteen buffaloes 8-10 years were selected so as to obtain a group of animals as near as possible to their maximal yield, which is usually at about 90 days after calving. Four sets of observations were made over consecutive periods of ten days each during May and June when the daily air temperatures varied from 71° - 113° F. During the first period the animals were splashed with bucketfuls of water for five minutes morning and evening every day two hours before milking. Body temperatures of the animals were recorded immediately before and one-half hour after splashing. During the second period no splashing was done. During the third period the animals were divided into two sub-groups - one of which was given daily splashing and the other none, their average duration of lactation at this time being 106.2 and 105.6 days respectively During the fourth period splashing was followed. Air temperatures, relative humidity, body temperature variations, the falls in body temperature after splashing and the corresponding average milk yields were recorded every morning and evening. The body temperatures after splashing dropped by 1° to 4° F. The milk yields during splashing periods were compared alternately with the yields during the preceding and following non-splashing periods (this omitted the effect of stage of lactation on production) and also the yields of the sub-group 1 were compared with those of the sub-group 11 and the differences were statistically analysed. Data presented show that the yields of the animals when splashed were greater than when not splashed and in every case the differences were highly significant. This experiment bears out the importance of body wetting of cattle during very hot weather in tropical countries.

When this is not practised as a daily routine the milk yield decreases. As has been dealt with elsewhere the heat dissipation of the cattle becomes difficult when the air temperature rises above 70 °F or so, normal physiological functions of the animal are disturbed; the body temperature rises and the milk production suffers.

The effectiveness of artificial cooling of the dairy cows in overcoming the depressing effects which the long continued periods of hot weather have upon milk production was reported from Georgia (238) Experimental Station. In this experiment the cows were artificially cooled by covering them during the day with light muslin cloths kept moist to stimulate cooling by evaporation. It was found that continued hot weather (temperature not mentioned) was the important factor in depressing the milk yields and artificial cooling was decidedly effective in easing the situation and no bad effects such as cold or other physiological disturbances were observed

That high environmental temperature affects milk production has been conclusively shown by Regan and Richardson (63). They conducted experiments with dairy cows of Holstein, Jersey and Guernsey breeds kept in an air-conditioned room in which temperature could be controlled keeping the other variables such as humidity and air movement etc. constant. Except for changes in environmental temperature uniform conditions were established. All cows were given a standard diet in accordance with their individual needs and were allowed free access to drinking water. The cows were held at each temperature for a period of from 5 to 10 days. The data for the first two days of each period were, however, not included in the averages, thus eliminating the possibility of any influence being exerted by the condition of the previous period. The following table shows the effect of high atmospheric temperature on the production of milk.

TABLE 24.

Air temperature °F	Body temperature °F	Milk production lbs. per day
40	101.1	29
50	101.0	28
60	101.0	27
70	101.3	27
80	101.8	25
85	102.7	23
90	103.7	20
95	105.1	17

The table clearly shows that as the atmospheric temperature increased from 40 to 95°F milk production graduall dropped from 29 to 17 pounds a day. It also appears from the table that between 40 and 70°F the decrease in production was not great but above 70°F the decrease was more marked. At 70°F the body temperatures of the animals started to rise and more markedly so as the atmospheric temperature increased further and further. So the decrease in milk yield at higher atmospheric temperatures can be related to the phenomenon of heat dissipation. When held at high temperatures for more than 24 hours heat production of the cow exceeds heat loss (cf. heat regulating mechanism), body temperature rises and the milk production decreases. Regan and Richardson's results also give further support to the observations made by others - Buckley (226), Kelley and Rupel (228), Speir (230), Dice (53) - that the low environemtnal temperatures as low as or even lower than freezing point do not affect milk production appreciably if the cow is protected from wind, snow and rain. Rather it appears that low temperatures within reasonable limit tend to increase milk production of well fed cows.

The observations made by other workers mentioned before were not completely free from the influence of many uncontrolled factors that accompany group experiments under ordinary conditions of dairy herd management, so little information of fundamental nature could be obtained from those observations. The experiment conducted by Regan and Richardson under controlled conditions, however, conclusively show that as the environmental temperature rises above the upper critical limit of heat regulation - 70 to 80 °F depending on the breed - the production of milk of a dairy cow is definitely affected.

Observations made by Rhoad[239] in Brazil also bear out the detrimental effect of high environmental temperature upon the production of milk. He reported that purebred European dairy cattle (in this case it was Holstein cows) imported in the tropics produced, on balanced rations, only 56% of their apparent capacity.

That high quality dairy cows of the European type produce best under relatively cool conditions is well illustrated by the results obtained by Villegas[219] with Holstein cows kept at 70 °F in an air-conditioned barn in Singapore. Cows in this barn produced an average of 24 pounds of milk a day as compared with the production of 9 pounds for a similar group in an open, ventilated barn exposed to tropical temperatures. This importance of the temperature effect on milk production is often ignored and the changes in production in tropical countries are attributed to other factors e. g. humidity, feed changes etc.

Bender[240] at the New Jersey Station, in an effort to evaluate the effect of temperature and humidity took records of temperature and humidity during 215 lactation periods of cows and stated that, "if the temperature factor does influence daily production, its effect is not for any definite period. The temperature factor probably works in connection with some other factor, such as humidity."

Continuing this study in co-operation with the Walker Gordon Laboratories, he found that humidity not temperature, appeared to affect milk production. The effect was not direct but made the animals to go off feed. He further stated that a humidity range between 50 and 75 appeared to be normal for dairy cows and that high producing animals were apparently more susceptible to humidity variations than the low producing animals. The details of the work were not available, so it could not be said how the production was affected by the fluctuations in the temperature and humidity. From the knowledge of heat regulating mechanism it seems quite likely that high humidity in combination with high temperature makes it more difficult for the cows to dissipate heat. It is not known what happened at the New Jersey Station regarding temperature and humidity. However, in view of the observations made by others, which have been already cited, it cannot be generalised that humidity, not temperature, affects production. When temperature and humidity are both operating together, temperature is decidedly the more important factor than humidity in affecting milk production.

That the high temperature in association with high humidity has a greater effect on milk production is supported by the observations of Watson (221) on the imported cows in Hong Kong. He reported that the climate of Hong Kong may be termed sub-tropical, actual tropical heat with very high humidity occurring only for seven months, March - October He made the following remarks regarding the effect of such a climate on dairy cattle of temperate origin in a large dairy herd on this island. "Cattle in the herd are all of European breeds. Since 1930, 440 Holstein, Ayrshire and Jersey adults have been added to the herd, these cows coming variously from Canada, Australia, Scotland and Holland. Importations usually arrive inthe winter. Until March or

April cows thrive and those which are in milk by this time yield up to the standards expected of them from their records. With the arrival of hot weather a marked depreciation occurs in the milk yield; this of course also occurs in locally bred animals but not to the same extent."

<u>Effect of temperature on butter-fat content, other constituent and physico-chemcial properties of milk</u>:

The factors which usually cause variation in the fat content of milk are:

(1) Breed,
(2) Size in breed
(3) Intervals between milking
(4) Day to day variation
(5) Stage of lactation
(6) Stage of milking
(7) Seasonal variation.

Various workers have found that the season of the year has a definite effect upon the percentage of butter-fat. With the change of the season the weather and feed conditions change. It will be seen that, apart from the changes in feed, temperature changes have been found to be mainly responsible for the seasonal changes in the butter-fat percentage.

Eckles (225) stated that the decline in test is usually noted soon after the cows are turned out to pasture in the spring. Towards fall the test begins to go up slightly. In an experiment at Missouri he (241) tabulated lactation records of 240 cows in the Missouri and Iowa Experimental Station herds and found that regardless of when lactation began, the percentage of fat plotted followed a curve for the year, being lowest in June and July and gradually rising to the highest point in December and January and then declining until mid-summer.

White and Judkins (242) concluded that milk tests lower in fat content in summer months than it does in winter months and that this variation is due to seasonal changes. He also found that the same relation exists in solid not fat. This conclusion was drawn from data taken on 49 cows over a period of 7½ years.

Weaver and Mathews (243) found, from a study of the Iowa State College dairy herd over a period of one year, that the fat test was highest during the first half of the winter or during January, gradually declining to the second half of the summer, August and early September when the lowest test occurred, and then increasing rather rapidly in the fall. Ayrshire and Holstein tests were approximately 0.6% lower in the second half of summer than in the first half of winter. Guernsey and Jersey tests were approximately 1.1% lower.

Ragsdale and Turner (244) found in a study of 4,100 Guernsey, Jersey and Holstein-Friesian Advanced Registry records that, irrespective of time of freshening, "the percentage of fat in milk when plotted follows a general curve, being lowest during summer months, gradually rising, reaching a peak during the winter months and then again declining during the spring and summer." The peak was reached in December at 4.75% and the lowest point in August at 4.32%.

Golding et al (246) studied the milk of a typical herd of healthy Shorthorn cows for five years at the National Institute of Research in Dairying, England, and they found that in each of the five years there was clearly a fall in the percentage of fat in the morning's milk in the spring when the cows were on young grass.

These works show beyond doubt that the season of the year has a definite effect upon the butter-fat test of milk. This test is the highest in winter when the cows are fed concentrates and lowest during the summer when the cows are turned on grass. Again another important difference between the summer conditions and winter conditions is the difference of temperature. So it appears that either the pasture or the temperature or the two together are the causes of the difference in the test. It has often been assumed that this decline in test during the summer months is the result of the feed.

Clothier (247) considering the differences in feeding practices between summer and winter seasons in Arizona, finds it "impossible to believe that the seasonal variations in butter-fat content of milk, observed in Arizona, are not due ~~to~~ directly to changes in feed." However, all other workers on this subject suggest temperature as a probable cause.

Eckles (225) states "the fact that the test is the lowest during the period the grass is the best (in early summer) and that it shows a tendency to increase towards winter when the grain feeding begins is easily interpreted to mean that the grass is the cause of the depression. Experimental work has shown that this is an error. The same decline in test during the summer and the increase in the fall has been found to occur in the same manner with cows receiving a typical winter ration throughout the summer and having no access to pasture grass." He further states that "the effect of the season is apparently the result of weather conditions, specially heat and humidity. It is found that during a period of hot, humid weather the percentage of fat is depressed while if the conditions are the reverse, dry and cool, the test is increased. This intensity of the effect of the season exerted through the weather conditions varies with the locality. It is apparently more marked in the southern than in the northern part of the United States.

Its practical importance is primarily that it explains the low tests of summer which, as noted, are often attributed erroneously to the feed." He continued that "the results of the seasonal effect are specially noticeable with high producing cows on official test. The summer tests under these conditions are often very dissapointing. It has also a bearing on the best time of the year to have cows freshen. It is found that fall calving gives a slightly higher test for the year than does spring calves, because it brings the highest milk yield and the highest test at the same time." It may be noted here that the theory of fall calving which will give the highest yield of butter in United States cannot possibly be applied in New Zealand where the cows are fed solely on pasture, hay and silage with little or no concentrates and where it has been found desirable, considering the economy of production, to have the cows freshen in spring so that the period of peak production of the cow coincides with the peak period of pasture growth.

That temperature and not the pasture is the cause of low test in the summer is also supported by the observations of Hills[(248)]. He stated that the results obtained in a study of the local creamery butter-fat tests of milk of 30 herds in Vermont during the months of May, June and July 1891, and July, August and September, 1892, points "strongly to the probability that when cows are put on pasture the percentage of fat rises as temperature falls, and falls as temperature rises. In other words, the percentage of fat in milk varies inversely with the temperature changes."

Various other workers have attempted to study the effect of temperature on the fat content and the composition of milk directly.

Weaver and Mathews[(243)] working with Ayrshire, Holstein, Guernsey and Jersey cattle, concluded that butter-fat tests were lower with higher outside and inside temperatures. They added that, as measured by regression coefficients, butter-fat tests were affected more by changes in environmental temperature than by other factors studied and further, that there were indications that variations in the butter-fat test were more closely related to variations in outside temperature.

Campbell[233] University of Reading conducted experiment with the object of finding out if there was any relation between high daily ranges of temperature in any one week or month and the number of low fats produced. By daily range of temperature he meant the difference between the maximum day temperature and the minimum night temperature and by low fats, the fats at or below 2.95%. The data show that the maximum range of temperature for the year (39°F) occurred in September and this maximum range coincided with an increased percent of low fats (16.5%) over the preceding month (13.5%). The author suggested that wide range of temperature variations was the cause of greater percentage of low fats in some months as compared with other months.

Brooks[249] found that when warming a stable for cows during the months of December to March there was a definitely lower fat test in the wing that was warmed to 55°F and maintained at this temperature than in the wing which was not warmed.

Armsby[119] quotes Speir stating that between 40° and 53°F temperature fluctuations have no appreciable effect on the percentage of fat.

Ragsdale and Brody[250] demonstrated the effect of temperature within the range of 37-70°F on the percentage of fat in milk. They made observations on ten cows during the months of March and April. All the conditions that could be controlled such as feed and exercise of the animals were kept approximately uniform throughout the period so that the effect of temperature on fat percentage was uninfluenced by other factors. The results show fairly conclusively that there is a relation between temperature and the percentage of fat with roughly an increase of about 0.2% in the test for a decrease of $10^{\circ}F$ in the temperature between the observed temperature limits (37° - $70^{\circ}F$

Hays[65] made similar observations in a study of the University of Missouri Dairy Herd over a period of 285 days starting in January, in which the environmental temperatures and the average fat tests were recorded. The temperature ranged from 85.5° to $24.5^{\circ}F$ and the tests ranged from 3.17 to 3.60%. He found that the lower the temperature the higher the test, the increase in test amounting to 0.079% for each $10^{\circ}F$ lowering of the temperature. However, because of the many variables the author did not consider this result as of much significance. In the second phase of the experiment the author conducted seven controlled temperature trials on two Jersey cows at $10^{\circ}F$ intervals of temperature, with all other conditions remaining normal. The range of temperature was from 92.7° to $27^{\circ}F$ - a spread of $65.7^{\circ}F$. This variation in temperature was accompanied by a total increase of 0.624% in the fat test, or an average increase of 0.095% for each $10^{\circ}F$ lowering of the temperature. The results are given in the following table.

TABLE 25.

A summary of all the controlled trials.

Trial	Total number of days	Average temp. for entire trial $^{\circ}F$	Average percent fat for entire trial
1	8	92.7	5.388
Vl	4	80.0	5.277
11	6	72.5	5.149
V	4	60.9	5.424
lV	5	52.3	5.646
111	6½	39.9	6.099
Vll	5	27.0	6.012

The data show that in the controlled trials there was a constant increase in the percentage of fat as the temperature dropped below 70° F. From 72.5° to 27° F there was a temperature range of 45.5° F and a total increase of 0.863 percent, or an average increase of 0.189% fat for each 10° F lowering of the temperature. This is nearly in accord with the observation of Ragsdale and Brody who reported a rise of 0.2% fat for each decrease of 10° F within the range of 70° and 30° F. In these trials of Hays there was an actual increase in the fat test above 70° F. The author believed this might have been due to increased metabolism, induced by higher temperature(cf. metabolism) or the result of disturbing the animals by the sudden changes from one temperature to another. In conclusion he stated "it would seem that there is a range of temperature between 70° and 90° F within which the lowest testing milk is produced. A variation in the environmental temperature either way will bring about an increase in the percentage of fat in cows milk," and "that all other conditions remaining constant, there is an increase of approximately 0.2% fat in cows milk for each 10° F lowering of the temperature within the limits of 70° and 30° F."

It is usually observed that there is a difference in temperature during night and day, temperature during night being usually lower than the day temperature. Has this temperature difference got anything to do with the comparatively lower testing of milk in the morning and higher testing in the evening? Uneven intervals between milkings under ordinary conditions are often considered to be an important factor causing morning milk to test low.

Ministry of Agriculture and Fisheries (1929) stated "So far as the percentage of fat is concerned, the intervals between milkings constitute the most important of the known factors associated with variations in the composition of milk."

On the other hand contrary to this Campbell (233) expresses the opinion that temperature variation per 24 hours "is a fruitful cause of morning milk being low in fat under twice daily milking conditions with uneven intervals." In another trial with six cows in winter Campbell (232) tried to determine the part played by the uneven intervals in this respect. He found that when a 15-hour interval was between night and morning milkings, a larger yield of milk with lower test was produced at the morning milking than was produced at night when the same interval was between morning and night milkings. He concluded that "night itself or factors operating at night tend to high milk production of low fat content. In a further trial he (234) milked the cows thrice daily at 6 a.m., 2 p.m. and 10 p.m. at eight hour intervals, took a total of 10,689 samples from individual cows and tested for fat. Of this number 1,262 or 11.8% fell to or below 2.95% of fat. The low fats were produced per milking as follows:

6 a.m.	-	38.9%
2 p.m.	-	34.4%
10 p.m.	-	26.7%

It is seen that the greatest number of low fats occurred in the morning milkings.

According to Campbell low temperature during the night is probably the cause of comparatively lower test of morning milk. This appears to be in contradiction to the observations made by other workers who found that low temperature tends to raise the fat test of milk. According to the observations cited before, the morning milk which is secreted during night under lower temperature conditions should be richer than the evening milk. It appears that the amount of milk yield has some influence on the test -

the test falling with increase in milk yield.

Woodward et al [231] observed that the buffer-fat content declined as the milk yield rose. If this is true the greater yield of milk in morning and not the temperature variation during twenty four hours is the cause of morning milk testing low

This is supported by the observations made by Houston and Hale [251] on seven cross-bred Shorthorn cows in north Ireland. Temperature differences between day and night were very small only 5-6 ^{o}F to produce any definite effect However after studying the effect of temperature seperately and statistically he stated that "changes in temperature are not the chief cause of the diurnal variations in yield and composition; and the diurnal variations in the milk yield, butter-fat yield and S.N.F. yield are independent of temperature changes." In conclusion he stated that the diurnal variations in the butter-fat percentage are mainly due to variations in the milk yield.

This observation was not, however, supported by Brooks [252] who studied the relationship between milk production and percentage of butter-fat. In order to determine the extent of this relationship he recorded the average amount of milk produced daily each month for all cows irrespective of time of freshening and correlated with the respective percentages of butter-fat for these months. The Coefficient of correlation was found to be $r = -0.1675$. This would indicate that the amount of milk produced was not a determining factor in the percentage of butter-fat when the effect of stage of lactation was eliminated.

Like other workers (Hays [65], Brooks [249], Ragsdale and Brody [250], Hills [248], Weaver and Mathews [243]) Brooks found a close inverse significant correlation between the percentage of butter-fat of cow's milk and the environmental temperature. He took records of 409 lactations of the cows in the Kansas Agricultural Experimental Station dairy herd over the period of fifteen years. In this study the author has made an attempt to eliminate such factors as stage of lactation and gestation, condition of animal, feeding and breed differences using the only records of 365 days duration and having the same number of animals freshening each month and the same number of animals from each of the four breeds, Jersey, Guernsey, Ayrshire and Holstein. The data are presented showing the average monthly environmental temperature, average daily production each month and average monthly tests for individual breeds. The environmental temperatures varied from 29 °F (January) to 78.5 °F (July). The highest average test (4.25%) for all breeds occurred in December (31.3 °F) and the lowest average test (3.83%) occurred in August (77.9 °F). The data was statistically analysed and the relationship was found to be r = -0.872 which is highly significant. The data for all animals have been also summarised by seasons, spring season consisting of March, April, May; summer of June, July, August; fall of September, October, November and winter of December, January, February respectively. The means for the seasons are shown in the following table.

TABLE 26.

Season	Milk per day pounds	Fats per day pounds	% of b.f. per day	Temp. °F.
Spring	26.2	1.0637	4.060	54.2
Summer	24.7	0.9631	3.899	76.9
Fall	24.2	0.9806	4.052	57.4
Winter	23.7	0.9990	4.215	30.5

It is noted from the table that the lowest mean temperature of 30.5 °F occurring in the winter season is accompanied by the highest average percentage of butter-fat, while the highest mean temperature of 76.9 $^{\circ}$F in the summer season is coincident with the lowest percentage of butter-fat. This is in agreement with the observations of other workers already cited.

Contrary to these observations, Bartlett (253), however, did not find any significant decrease in the fat test of the cows kept in a room artificially heated to about 80 $^{\circ}$F by means of hot water radiations, as compared with the test of the control animals housed at the prevailing air temperature of about 40 $^{\circ}$F. Two pairs of animals were used; one from each pair was subjected to high temperature while the other one was kept as control at the air temperature. The animals were changed over from hot to cold and vice versa during the course of the experiment. Feeding, milking, stage of lactation and general management etc. were almost identical for each pair. The results show that a significant change was observed only in the case of S.N.F. where an average decrease of 0.153% solids in the fat-free milk occurred in 44 cases to 1. The milk yield was reduced by 0.16 lb. per day and the fat % by 0.04, neither being significant. The author concluded, "although the experimental conditions of temperature were continually higher than English summer conditions, the experimental depression in milk quality was relatively small. It appears reasonable to suppose, therefore, that high temperature is not the only factor responsible for low quality summer milk."

The number of animals used by Bartlett was small. Moreover he did not subject the animals to intermediate temperatures between 40 $^{\circ}$ and 80 $^{\circ}$F. Hays (65) found that the fat content somewhat increased after 72 $^{\circ}$F and that might be the reason why Bartlett did not find any significant difference in the test between 40 $^{\circ}$ and 80 $^{\circ}$F. Therefore it cannot be said from Bartlett's observation that high temperature does not decrease fat percentage. On the contrary, the evidences cited before conclusively show that high environmental temperatures do decrease and low environmental temperatures do increase the fat content of cow's milk.

That the environmental temperature, particularly the higher temperatures have influence not only on the composition of milk but also on its physico-chemical properties has been shown by Regan and Richardson[63] under controlled temperature conditions. They kept six pairs of high producing dairy cows, including Holsteins, Jerseys and Guernseys in a psychometric room, varying the temperatures from 40° to 90° F. The animals were held at each temperature for 5 - 10 days and the data for the first two days were excluded in order to eliminate the influence of the previous period. Excepting temperature, humidity, feed and air movement etc. were kept uniform. The results obtained by them are given in the following table.

TABLE 27.

The influence of temperature of environment on the physico-chemical properties of milk and milk fat.

Temp. °F.	Fat %	S.N.F. %	Casein %	Freez -ing point -°C	P.H.	Renin coag-ulat-ion Min. Sec.	Milk fat constants	
							R.M. value	Iodine number
40	4.2	8.26	2.26	0.536	6.53	4.10	28.80	30.51
50	4.2	8.26	2.23			3.50	29.36	31.53
60	4.2	8.06	2.03			4.09	28.16	
70	4.1	8.12	2.05	0.538	6.56	4.13	28.73	31.96
80	4.0	7.88	2.07			4.00	29.14	31.77
85	3.9	7.68	1.93			4.38	28.58	31.34
90	4.0	7.64	1.91			4.49	28.15	31.44
95	4.3	7.58	1.81	0.525	6.65	5.05	25.65	37.12

The table clearly shows that the changes in the composition and properties of milk became marked with a definite trend as the temperature of the room rose to or above 80°F. There was a marked decrease in the percentage of S.N.F. andin the protein content. There was a lowering of the freezing point depression and the lengthening of the time of rennet coagulation. The values for the percentage of butter-fat and the pH tended, however, to increase above 85°F. Between 90° and 95°F there were marked changes in the characteristics of the milk fat, as indicated by a lowering of the R.M. value and an increase in the iodine number. The percentage of butter-fat remained constant between 40° and 60°F. after which it started to fall gradually until 85°F. The fall between 80° and 85°F was rather sharp. It started rising sharply again as the temperature increased above 85°F and the test at 95°F was even higher than that at 40°F. No explanation has been offered by the authors regarding this rise in test above 85°F. The similar rise in test at higher temperature was observed by Hays[(65)] but the rise took place above 72°F. In both these experiments carried out under controlled conditions the test of cow's milk responded to environmental temperature in similar way. According to Hays the lowest test occurs within the range of 70 - 80°F above and below which the test rises. According to Regan and Richardson this range lies between 80 and 85°F. The two ranges as found by these workers individually, although somewhat differ, are reasonably close. This slight difference is not unexpected considering that this range will depend upon the upper critical temperatures of the animals. The upper critical temperatures again will depend, apart from breed differences and individuality of the animals, upon (1) sweating mechanism, (2) relative humidity and air movement, (3) nature of insulation (fur, feathers, fat);

(4) ratio of surface area to body weight; (5) body temperature, (6) other factors, such as acclimatization.

The influence of acclimatization is shown by Gelino et al [254] in their work on rats. They found that in rats the body temperature began to rise at 32°C (89.6°F) if acclimatized to 10° - 12°C (50° - 53.6°F), at 33°C (91.4°F) if acclimatized to 12° - 18°C (53.6° - 64.4°F), and at 35°C (95°F) if acclimatized to 29° - 32°C (84° - 89.6°F. So it is not likely that all these conditions were similar in both of Hays' and Regan and Richardson's experiments. Moreover in Hays' work only Jersey cows were used and in Regan and Richardson's work Jersey, Holstein and Guernsey cows were used. The latter workers in the same experiment took the body temperatures of the animals and they found that the upper limit of heat regulation for these animals was between 80° and 85°F above which the body temperatures of the animals started to rise distinctly and the composition of the milk was affected. They stated that "until the cow becomes hyperthermic, her milk is quite uniform in composition and behaviour. Significant changes occur in the milk after the 'upper critical temperature' has been reached."

Regan and Richardson's observation that the time of rennet coagulation and pH of milk increased at high environmental temperatures is supported by the data presented by Freborn et al [34]. The data (see Table 28) show that, as in the case of the effect on body temperature, there are distinct breed differences in the change of milk characteristics at higher temperatures.

TABLE 28.

Room temp. °F.	Body temp.		Rennet coagulation				Hydrogen ion concentration.	
	Holstein °F.	Jersey °F.	Holstein min.	sec.	Jersey min.	sec.	Holstein	Jersey
75	102.3	101.5	4	35	4	11	6.59	6.57
80	103.3	101.5	5	31	3	45	6.63	6.56
85	103.8	103.1	6	06	4	46	6.64	6.75

As this table shows the Holsteins lost control of their body temperature at 80°F with concurrent changes in the composition of the milk. The Jerseys maintained their normal body temperature at 80°F and milk characteristics also remained normal. The higher environmental temperatures, thus affecting the body temperature affected the composition of milk and differently in different breeds.

These changes in the physico-chemical properties of milk at higher environmental temperatures can probably be best explained on the basis of blood changes brought about to facilitate heat dissipation.

Dill et al [31] have shown that in dogs the lowering of the serum protein takes place at high temperatures. If a similar change occurs in cows it might well explain the reduced protein content of the milk of cows.

As for the freezing point Davies [255] states "the osmotic pressure of milk and hence the depression of the freezing point, is due chiefly to the contained lactose and soluble salts. The fat has no effect and the effect of protein is negligible." So also Eckles [256] stated that milk sugar and ash determine the freezing point of milk. The data produced by Regan and Richardson show that between 40 and 70°F the freezing point of the milk very slightly lowered but at 95°F it became significantly high. The higher freezing point as obtained by these authors indicates a decrease in the soluble components of the milk. Since the cow does not sweat, the blood serum chlorides show little or no variation with increasing temperatures (Freeborn et al[34]) and as a result the sugar content of blood may decrease at these temperatures. Lee and Scot[257] found in their experiments with cats which is also a non-sweating animal, that a hot environment resulted in the lowering of the cat's blood sugar. It would seem probable, therefore, that the rise in the freezing point at higher temperatures is due to lowering of the milk sugar content which, in turn, may be due to the lowering of the blood sugar content of the animals at these temperatures.

As regards the increase in the pH of milk at higher temperatures, Regan and Richardson stated that this "may be best accounted for by the decrease in the milk colloid content as affecting membrane equilibria." This can also be explained by Haggard's[258] belief that the hydrogen ion concentration of blood is decreased when the body becomes overheated.

Regan and Richardson stated that the increased time of rennet coagulation at higher temperatures can be explained partially by the increased pH and that the lower calcium ion concentration might also be involved.

The changes in the characteristics of the butter-fat secreted at high temperatures can be best explained as the result of hyperthermic under-nutrition or "physiological" under-feeding as called by Eckles and Palmer[259]. Regan and Richardson observed that at high temperatures the appetite of the animals greatly diminished.

The decrease in R.M. value and the increase in iodine number at higher temperatures is supported by the observations of Eckles and Palmer[259] who stated that all types of under-feeding (induced and physiological) have marked effects on the physical and chemical contents of the butter-fat which are characterized by a decline in Reichert-Meissl number and saponification value and an increase in the iodine value.

It can be concluded from these observations that low environmental temperatures as low as or even lower than freezing point do not affect the production of dairy animals if they are fed well and protected from severity of weather such as snow, storm and rain. Low temperatures rather increase the fat content of milk. High atmospheric temperatures - higher than upper critical temperatures (70 - 80 ^{o}F) - affect the normal physiological functions of the dairy animals such as body temperature, respiration rate and metabolism etc. As a consequence the milk yield is lowered and the composition and physico-chemical properties of milk are seriously affected. At high temperatures the fat percentage (withih certain range of temperature), S.N.F. percentage, casein percentage and R.M. value decrease; the pH of milk, iodine number and the time of rennet coagulation increase; and the freezing point rises. The extent to which the production of milk and its composition and properties are affected depends somewhat on the breed and can be related to the efficiency with which a dairy cow can dissipate surplus body heat under the conditions of high atmospheric temperatures.

E. INFLUENCE OF TEMPERATURE ON THE DISEASE INCIDENCE AND DISEASE RESISTANCE:

A detailed study of this section is beyond the scope of this dissertation; nor any definite conclusion regarding the direct influence of environmental temperature on disease incidence and disease resistance of dairy cattle can be arrived at because so many other factors are involved. Thus temperature, by affecting the metabolic and other physiological functions which have been already dealt with may predispose the cattle to diseases and here disease incidence and resistance will be only a secondary effect of temperature.

Disease Incidence:

Occurrence and incidence of a disease in a particular country may be greatly influenced by its climatic factors such as temperature and humidity because these factors have a great influence on the life history of disease producing organisms.

The optimum temperature of the pathogenic bacteria is that of the body $37^{\circ} - 39^{\circ}$ C ($98.6^{\circ} - 102.2^{\circ}$ F). Unfavourable temperatures, both high and low, may profoundly affect a particular species of bacteria, preventing growth, altering virulence and preventing sporulation (Gaiger and Davies[146]). For example in the case of anthrax bacillus growth ceases below 12° C (53.6° F), sporulation ceases below 16° C (60.8°) and above 42° C (107.6° F) virulence is permanently decreased and above 43° C (109.4° F) growth of bacillus ceases. Low temperatures are usually less destructive to bacterial life and many organisms survive freezing temperatures e.g. tubercle bacillus has been found alive in animal tissues frozen at 15° F for several years. Higher temperatures, on the other hand, act more or less fatally upon bacteria.

Again moist heat is more severe to bacteria than dry heat (Klimmer[147]). Roemmele[148] observed that the warmth and the presence of moisture in the air shorten the incubation period of foot and mouth disease in pigs and favour a severe attack. Cold and dry conditions on the other hand increase the incubation period and favour mild attack.

Similarly the climatic factors have great influence on worm parasites. Conditions of temperature and moisture in the tropics are ideally suited to the survival of many parasites and facilitates their dissemination (Culbertson[149], Smith[150]). The chances for exposure to these parasites is then greaeer in the tropics and since this exposure may also involve a larger number of parasites, the chances for more severe infestation and infection would be greater.

Effect of temperature has been noted on the growth and development of nematodes infesting pigs (Otto[151], Cram[152]) and sheep (Fallis[153]). Schwartz[154] stated that low temperatures have a greatly detrimental effect on the development and vitality of eggs and larvae of swine kidney worm. In U.S.A. the centres of kidney work infestation are confined to the southern states and in Australia to the north-eastern coastal belt, mainly because temperatures in these areas are comparatively higher (Ross and Kauzal[155]).

Tick infestation and tick fever have been a serious obstacle to the cattle improvement in the tropics. Tick fever is a specific disease of cattle caused by a protozoan parasite the piroplasma bigeminum or Babesia bigeminum (Kelley[156]). The various synonyms of tick fever in different countries are - Texas fever, bloody murrain, Southern cattle fever (U.S.A.), bovine malaria (Europe), triesteza (South America), heart water, red water (South Africa, Great Britain and Australia and piroplasmosis. In natural conditions this disease is spread by cattle tick. Climatic factors such as temperature and humidity appear to have influence on tick infestation. Kelley (156) stated that the disease exists in its most acute form during summer and autumn months in Australia. Myers (157) reported the presence of cattle tick in New Zealand. The New Zealand cattle tick, however, does not carry the tick fever. This tick is mainly found in North Auckland peninsula and spreads along the east coast and the west coast up to Taranaki. Very rarely tick is found in other parts of North Island and in South Island. This distribution of tick in the North Auckland peninsula and along the coastal regions of North Island has been attributed to an "equable and warm climate" in these areas. Myers stated that "tick is a tropical insect and warmth and high humidity are the necessary climatic factors for the tick," and that the climatic factors, "particularly the warmth has been a marked feature in keeping it far from spreading further south in New Zealand. It has been further stated that dry heat as well as excessive moisture have severe effects on ticks, especially when they are off the host. Van Saceghem (158) found that ticks do not transmit East Coast fever in Belgian Congo at about 8,000 feet and that the heat factor evidently affects not only the number of ticks at high altitude but also the virulence of organism inoculated by them. He believes that it is the low temperature on the mountains and high plateaux that prevents the ticks from propogating the disease. Similarly Forthingham et al (159) reported that East Coast fever cannot exist for a prolonged period in cold atmosphere at high altitudes in South Africa and Kenya and that the common vecting tick (R. appendiculatus) cannot survive and become established in these areas.

These observations indicate that temperature in combination with humidity and possibly other climatic factors may influence the occurrence and incidence of livestock diseases in a particular country or in a particular season and may explain to some extent the preponderance of some diseases e.g. Rinderpest, F. & M. disease, Anthrax, Blackleg, prioplasmosis and ectoparasites, tick, biting flies, mosquitoes, Tsetse fly etc. in the tropics; and others e.g. T.B. Brucellosis, mastitis etc. in the temperate countries.

Disease resistance:

Culbertson[149] stated that the climatic factors, temperature and humidity seem to be significant in natural resistance of man to amoebic infection and that the individuals who have the infection often improve on removal from tropics to temperate zones. Mills[32] collected large number of statistics on the morbidity and mortality rates in man from T.B., acute respiratory infection, acute appendicitis and correlated them with atmospheric conditions. His observation shows that tropical climate with the consequent difficulty of body heat loss, produce retarded physical development and lowered resistance to infection, as contraste with the much more vigorous existance and heightened resistan to infection enjoyed by people of cooler countries where "climatic stimulation" is greater. However, in drawing any conclusion from this observation, other factors such as bette sanitation and better nutrition as prevalent in cooler countries must be considered.

The effect of temperature on disease resistance has been observed experimentally in mice by Weigmman[160], Colvin and Mills[161]. Weigman's observation under varying conditions of temperature (50^{o} - 68^{o} F) and humidity (60 - 100% indicates that the mice when infected with definite amounts of different disease producing organisms, die earlier in an atmosphere heated to 68^{o} F and saturated with moisture

(100% humidity) as compared with 58° F and 60% humidity.

Colvin and Mills[161] made an interesting observation varying temperature from 65° to 95° F with humidity kept constant (65%) and injecting different doses of infections organisms (haemolytic streptococcus). His results conclusively show that the mice kept at 90° F died more quickly than those kept at 65° and 70° F and that the former group succumbed with only one-fourth the culture dose needed to kill those of the latter two groups. In conclusion the author stated that "the difficulty in disposing the surplus body heat and lowered metabolism under high temperature conditions result in a "sharply reduced ability to fight infectious invasion."

In rabbits Cralley[162] observed the effect of temperature and humidity on the capacity of the animals to remove bacteria from the lungs when they were made to inhale very large numbers of bacteria. He found that under normal conditions (air temperature 78° F and relative humidity 45%), 80% of the organisms were removed in the first hour and 90% in three hours. When the animals were subjected to extremes of temperature (100° F and 30% humidity or 39° F and 80% humidity) or first to one extreme and then to another, the rate of removal was definitely depressed. However at the lowest temperature (39° F) it cannot be said whether the effect was due to low temperature or high humidity. It appears from these observations that the extremes of temperature, either too high or too low, affect the resistance of an animal to diseases. The results obtained with mice that the high temperatures combined with high humidity lowers the natural résistance to disease and that it is a matter of ease or difficulty with which an animal can dispose of surplus body heat have also been observed in European cattle when they are exposed to high tropical temperatures. This point and the heredity factor in disease resistance will be made clear in the discussion that follows.

Zebu versus European cattle:

The importance of hereditary factors in controlling the physiological functions of the animal body and thus affecting the animal's power of resistance or susceptibility to diseases, has been fully recognized in livestock breeding.

Several workers have, in fact, by selective breeding with a view to greater immunity to certain diseases succeeded in producing strains of fowls (Lambert (163), Hutt and Bruckner (164)) and mice (Gowen and Schott (165)) possessing a very high degree of resistance to certain diseases - typhoid and malignant growth in fowls, and typhoid in mouse. Similarly Cameron and others (166) were able to develop strains of pigs possessing a considerable degree of resistance to contagious abortion caused by Brucella Suis. Lambert et al (163) some years ago, indicated the existence of genetic differences in horses in regard to their susceptibility to a certain type of horse sickness. An example of racial differences in the resistance of man to malarial infection and worm infestation is found among negroes and European (Cameron (167), Otto (168)). Negroes are highly resistant and the whites are highly susceptibile to these diseases.

These hereditary racial differences which have been brought about by natural selection through ages have been observed between the Zebus and the European cattle.

Kelley (2) reported that the Zebus possess a high degree of immunity to tick infestation and tick-borne diseases in Australia whereas the European breeds of cattle are very much susceptible. Bonsma (169) stated that the Zebu cattle in Africa have proved to be protected against all the tick-borne parasites.

Shrode and Lush (170) reported that "Texas fever is a serious disease for European cattle but is such a mild disease with Zebus that many cattlemen think the Zebus and their higher grades are immune." They further stated that careful examination, including temperature readings after inoculation, shows that the immunity is not complete, as some at least among them do have the disease although in such a slight form that they scarcely seem sick.

Schmidt (171), at the Texas immunization station innoculated many pure and grade Zebus with blood from cattle carrying piroplasmosis. He found that the Zebus have such a high degree of resistance that it practically amounts to a physiological immunity. Edwards (172) with years of experience in India stated that Indian cattle are highly resistant to piroplasmosis and it is not regarded as a serious infection of indigenous stock. Curson (173) reported that the Zulu cattle in South and Central Africa possess hereditary resistance to heart water, red water and gall sickness. Bonsma (169) made observation over a period of seven years on the resistance to tick infestation of Africaner cattle and cattle belonging to exotic European breeds kept at Mara Experimental Station. His data show that 61% of the calves of European breeds died from tick infestation within the average age of five months whereas only 5% of the Africaner calves died with eleven months of age. Both Bonsma (169) and Kelley (2) observed that the resistance to tick infestation increased with the percentage of Zebu blood in the off-spring. Bonsma further stated that the differences in the tick infestation between Zebu and European cattle can be correlated with the differences in the number of ticks they harbour. On the basis of unit area about 71 - 74% of all the ticks counted occurred on the exotic breeds and only 26 - 29% were found in the Africaner cattle. This tick repellance of Zebus is due to some morphological characters (Bonsma[169], Kelley[11], Babcock and Clausen[174]), which again are inherited. These characters are:-

(a) The skin of the Zebus secretes sebum which with sweat gives a repellant odour repugnant to insect life.

(b) Their skin is very tough and dense and difficult to puncture.

(c) Zebus have short coat which restricts lodgement and does not provide shelter for ticks.

(d) In the Zebus the panniculus muscle is very much well-developed, and admits of much skin movement. This can be used to twitch flies off from the body.

(e) The tail which is devoid of vertebrae at the tip can move more freely and help in brushing the ticks off.

In addition to this, since the Zebus can regulate heat better, posses small stomachs and are able to remain relatively long without water (Kelley[11]), they remain outside in the sun in the open paddocks rather than in shady places, water holes and cattle camps, where the population of the seed ticks are the greatest. On the other hand the European breeds without these Zebu characteristics rest in such heavily infested areas for a much greater length of time and become highly infested.

With regard to other diseases Edwards[172] stated that the Indian cattle in the plains, where the atmospheric temperature is very high, are 60% more resistant to rinderpest than British-bred cattle. "Some strains," he stated, "are more resistant than others." He considers that "the resistant strains have resulted from natural selections during waves of infection which, with varying intensity, have swept through the cattle population of India periodically since time immemorial."

As regards foot and mouth disease and anthrax, he stated that the Indian cattle are more resistant than British breeds but that no such differences exist with regard to tuberculosis. Carmichael [175], however, stated that all through Equatorial Africa, where Zebu type of cattle predominate, bovine T.B. is rare and suggested that these cattle have specific resistance to tuberculosis. The long-horned Ankole type of cattle in Uganda, which are apparently not Zebu, has been stated to have a very high susceptibility to T.B. He also reported a marked resistance of Zebu calves to subcutaneous injection of tubercle bacillus of standard virulence whilst the Ankole calves showed little resistance.

Hornby [176] quoted from several reports to show that T.B. is generally regarded as a comparatively unimportant disease in South Africa. Discussing the low incidence of disease in Tanganyika Territory he stated that the native races of cattle, particularly Zebu, are more resistant to infection than the imported European cattle.

It appears from all this evidence that temperature, both high and low, by affecting the growth and development of the disease producing organisms may have a profound effect on the incidence of disease and that temperature may greatly influence the natural resistance of the live stock including cattle. Prolonged exposure to cold, particularly if nutrition is not adequate, produces an excessive loss of body heat and energy in cattle and similarly prolonged exposure to high temperature affect greatly the normal metabolic and other physiological functions, such as respiration and body temperature. In either case the animal loses condition and vitality with the consequent lowered resistance to disease.

In regard to disease resistance under tropical conditions Bos Indicus cattle are genetically superior to

Bos Taurus cattle. At higher temperature and humidity Bos Indicus is more efficient in regulating body heat and as such is more resistant to tropical temperature than the Taurus cattle. Temperature, affecting the vital functions of the European cattle in the tropics, may predispose them to tropical diseases. No doubt temperature is an important factor responsible for the failure and degeneration of European cattle in the tropics (cf. adaptability).

VI.

INFLUENCE OF TEMPERATURE ON ADAPTABILITY OF DAIRY CATTLE.

The optimum development, production and reproduction in farm animals can be attained only in an optimum environment. "Maximum manifestation of an animal's genetic potentialities can occur only when the environment is optimum, that is, where the prevailing conditions with regard to climate, level of nutrition, general health and animal management are so favourable, that the animal can express the whole of its genotypic make up, in its phenotype. If the environment is less than optimum this is obviously impossible." (Bisschop[260]).

The importance of environment has been observed in the cases of importing European breeds of cattle in the tropics in an attempt to improve the production of the tropical cattle. Holstein-Friesians, Ayrshires, Shorthorns, Jerseys imported in India (Wright[13], Olver[261]), Hong Kong (Watson[221]), Phillipines (Manresa and others[67][68][69][70]) and in Jamaica (Hammond[252]); Holstein-Friesians in Singapore (Villegas[219]) and in the sub-tropical part of U.S.A. (Williams[264]); Sussex, Aberdeen Angus, Hereford and Shorthorn in Brazil (Rhoad[73][74][75][76]), South Africa (Bonsma[44][88]), Tanganyika (French[265][266]) and Kenya (Daubney[267][272]) have failed to adapt to the tropical environment. When these cattle are bred for several generations in the tropics, they degenerate and produce little. When these are bred pure by importing bulls of the same breed the off-spring produce even less because the constitution of these animals is not suited to the tropical environment. When they are crossed with the native cattle which are either Zebu or contain a high percentage of Zebu blood, the half-bred off-spring produce much more than the purebred animals and are well suited to the tropical conditio

In the dairy breeds it has been found that as the proportion of European blood increases from ½ to ¾ or ⅞ in the grade animals, they degenerate, changes take place in types and the milk production suffers.

Hammond (262) studied several generations of some native-bred European dairy or dual purpose breeds and some imported pure stock in Jamaica. He found that the stock which had been native-bred for several generations were of markedly different type from the original (see plate 4). The changes consisted of coarseness, that is, proportionately larger size of head and legs, with flat-sided and shabby barrels, and comparatively large horns (where present), and the characters as a whole approached those of the native stock.

The degenerative changes of the European breeds in the tropics have been attributed to a combination of factors such as climate, nutrition and sublethal infection of tropical diseases (Hammond (261)(262)(268), Olver (261), Bisschop (260), Teodoreanu (269)).

It has been stated that the improved European cattle grow more rapidly than native tropical cattle and hence require more food, including more bone-building material. But the tropical pastures during the dry season are of very low feed value, high in fibre and low in protein content. In the tropics the growth of the grasses is limited by rainfall and starts with the onset of wet season and is reduced during any intervening short dry periods. In some areas phosphorus deficiency occurs, apart from the effect of drought, due to deficiency in soil (Kaura (24)) and the cattle, especially improved European breeds, show low blood phosphorus, poor bone growth and poor production (Bisschop (260)). Therefore the main problem of feeding in the tropics would appear to be the supply of less fibrous,

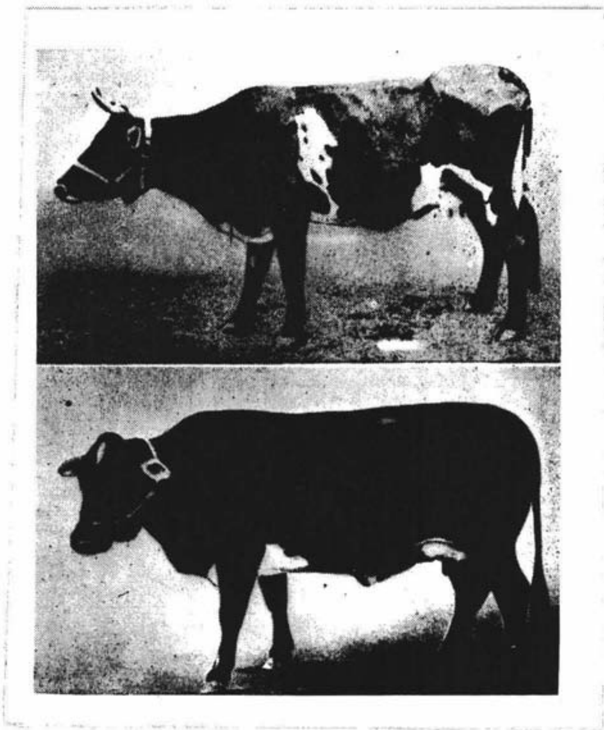


PLATE 4.

Degeneration in a high-grade Jersey cow (above) in the tropics. Her daughter below by a Sahiwal Zebu bull is not only of better constitution, but has also given higher milk yields (Hammond, J. (263)).

protein rich and, if possible, succulant feeds during the dry season. Hammond suggests that ensilage of grass or forage crops in the early stages of growth or irrigation of pastures may be successfully practised to overcome the problem of nutrition.

The sublethal infection of tropical diseases such as tick fever, according to Hammond, reduce the vitality of imported European cattle, cause general unthriftiness, prevent the development of their body form and thus lead to the degeneration changes.

However, the most important limiting factor to the adaptability of the European breeds in the tropics appears to be the high atmospheric temperatures. Thus Olver (261) stated that "...... the work that has been done in India, by cross-breeding with exogenous sires, tends clearly to indicate that ability to withstand a tropical sun is one of the most important factors affecting acclimatization in tropical countries."

Villegas (219) reported that even when additional green feed was added as supplement to the pasture allowance of Herefords imported in the Phillipines, the animals were found to reduce in flesh gradually. "Reproduction went on fairly well but a number of young were either weak or born dead. Those that survived became stunted, thus failing to reach normal size at maturity." Gonzelez (270) reported about the purebreds and grades of the Jersey, Shorthorn, Ayrshire and Holstein imported in the Phillipines from U.S.A. and Australia. He stated that "these animals are generally imported in calf, kept in barns under very sanitary condition and given imported feed similar to what they were fed at home. They milk well in the first calvings, but soon deteriorate in health and production and die apparently from no other cause than simple inability to stand local conditions. The animals fall an easy prey to rinderpest and foot and mouth diseases."

He further stated that while imported dairy cattle manage to live for a time and reproduce, it has been almost impossible to raise satisfactory calves from them. "The calves born are generally weak and most of them die before weaning. Those that survive this period turn out to be inferior individuals which are not worth keeping."

Bisschop (260) observed that, in South Africa, even when the nutrition was improved by supplying bone meal the purebred and high grade Red Polls deteriorated greatly in type and quality whereas the native cattle rather improved.

These observations clearly show that provision of good nutrition and improved sanitation alone cannot prevent the degeneration of the temperate cattle brought in the tropics. That the most important factor is the high tropical temperature is not realized by many breeders.

In Kenya and South Africa the European cattle have acclimatized quite well at high altitudes where the temperature is milder than in the plains but where the feed and disease conditions, apparently, are not much different (Daubney (267), Bonsma (44)(88)). In conclusion Daubney state that European stock can be raised in those areas of Kenya where the mean annual temperature does not exceed 65 °F provided the management is good and nutrition adequate and that, in the areas where the mean annual temperature is higher than 65 °F., the improvement of native cattle for milk production should be effected by the use of high class Indian Sahiwal bulls.

The explanations offered by Bonsma (44)(88) as regards why the Zebus are suited to the tropics and the European cattle are not, appears to be the right ones. According to what he calls "metabolic explanation," the European cattle have become adapted to cold temperature and high degree of feeding and their physiological functions have developed accordingly whereas the Zebus have adapted to high temperature and low standards of feeding. Energy for action, growth and production can be derived only from metabolism of food stuffs. In the case of European cattle, under high atmospheric temperature conditions in the tropics the animal consumes less (cf. Food Consumption Utilization) and the body slows down metabolism in order to reduce the heat increment of feeding and thus prevent overheating of body. The result is that the animal suffers from 'tropical' under-nourishment.

Therefore, the whole question of adaptation is one of rate of heatexpulsion. The Bos Taurus cattle, because of their comparatively larger size and less body surface per unit of live weight, thicker skin, absence of sweat glands, absence of pigment in the skin and presence of longer coat, is much less efficient in the expulsion of surplus body heat. As a result their vital physiological functions, respiration and body temperature, are seriously affected and they become undernourished and highly susceptible to tropical diseases. The Zebus, on the other hand, being more efficient in the elimination of extra body heat are comparatively much more resistant to tropical temperatures. This is the reason why the Zebus imported in tropical and sub-tropical countries such as Brazil, Australia, Phillipines have acclimatized so successfully.

It appears that the problem of adaptability and hence the problem of improvement of dairy production in a tropical country can be tackled from two angles, (1) by improving the environment or (2) by evolving breed or breeds of dairy cattle suited to the climate of the country. Attempt in the direction of the first point has been made by providing an air-conditioned barn for Holstein-Friesian cows in Singapore (Villegas (219)) and significant results have been obtained. Sprinkling cold water on the animal body on hot summer days (Sinha and Minnet[237], Seath and Miller[271]) in order to lower the respiration rate and body temperature and maintain production has met with some success. The use of some substitute for sweat glands, perhaps some spongy, porous covering such as rubber or acetate sponge or a cover of some such fabric as jute, which holds moisture, may be feasible, but such improvements of environment are of temporary nature and are not economical under commercial conditions. The second possible way of overcoming the problem of adaptability - by developing suitable breeds for the tropics - will be dealt with in the next section.

VII.

BREEDING DAIRY CATTLE IN THE TROPICS.

Milk production of the native cattle (Zebu) in the tropics is very poor and so there has been felt a great need in the tropical countries for the improvement of dairy production by breeding better dairy cattle. It could be stressed here that the dairy production in the tropics cannot be improved by breeding unless it is coupled with better nutritional and managemental practices.

The most important point that should be remembered in attempting to breed improved dairy cattle in the tropics is that the Zebu cattle are genetically suited to withstand the rigours of the tropical climate - high temperature and high humidity - where as the highly specialised dairy breeds of temperate origin are not. Ability to withstand tropical environment is as much an inherent characteristic of breeds of cattle as capacity for milk production.

This point was overlooked or not properly understood by the early breeders who attempted to increase the dairy production in a tropical country by importing European breeds. The problem that faces a tropical dairy breeder is to combine the capacity for high production with the high resistance to tropical heat and humidity.

The breeding methods that have been or can be followed for improvement of tropical dairy cattle are as follows:-

(1) Importing European breeds and maintaining them as purebred - the result has been an absolute failure.

(2) Grading up native cattle with bulls of European breeds - this also has resulted in failure. The purebred as well as the high grade animals fail to adapt to tropical heat.

(3) Crossing and back-crossing to the native bull or to

the European bull in order to retain, in the off-spring, a certain percentage of Zebu blood (50%) desirable for high heat tolerance and high production. Such methods necessitate the maintenance of at least two breeds, one of which is unsuited to the environment. More-over such methods cannot bring about any improvement of permanent nature and cannot be followed as a breeding policy for the entire country.

(4) To evolve a new breed by crossing the native cattle with a suitable European dairy breed followed by inbreeding of the cross-bred animals in combination with rigid selection and thus fixing the high milking capacity and high heat resistance in the off-spring. This has been done in developing a new beef breed, Santa Gertrudis (Rhoad (275), Manresa (274)) in the King Ranch, Texas, which possesses high productive efficiency and high heat tolerance. This is an example showing that new and improved breeds of cattle for the tropics can be evolved through judicious cross-breeding of Zebu and European cattle combined with skilful selection and intelligent mating.

The foundation bull of Santa Gertrudis breed was "Monkey" a cross-bred Zebu with Nellore blood predominating and with some percentage of Durham and Shorthorn blood. He was bred on the Zebu-Shorthorn cross animals. Method of breeding used in the formation of Santa Gertrudis breed was as follows:-

Brahman ($\frac{1}{2}$) - Durham (7/16th) - Shorthorn (1/16th) "Monkey" X Brahman ($\frac{1}{2}$) - Shorthorn ($\frac{1}{2}$)

Brahman ($\frac{1}{2}$) - Shorthorn ($\frac{1}{2}$) X Brahman ($\frac{1}{2}$) - Durham (7/32nd) - Shorthorn (9/32nd)

Brahman ($\frac{1}{2}$) - Shorthorn ($\frac{1}{2}$) X Brahman ($\frac{1}{2}$) - Shorthorn (25/64th) - Durham (7/64th)

Brahman - Shorthorn - Durham (Santa Gertrudis)

Santa Gertrudis animals are claimed to breed true to the type.

Such a breeding method, however, is very much time consuming, should be extended over a considerable number of generations, requires great skill and is also beset with hazards, for it necessitates the mating of cross-bred sires with cross-bred dams; if not done systematically, no results can be obtained and all labour will be lost. Such methods can be undertaken by Government but not suitable for individual breeders.

(5) Grading up of native cattle with bulls of high milking Zebu breeds such as Sahiwal, Sindhi etc. This is a very practical method and is being followed in parts of Kenya where the use of Sahiwal bulls has been advocated (Daubney[267]).

(6) Developing dairy strains through selection and breeding from indigenous cattle. This method is suitable only if the native cattle possess potentialities for high production of milk. This method has been adopted by India Government and herds with high milking capacity have been developed on the Government Farms (cf. Production in India).

One or more of these methods have been or are being tried in various tropical countries (Fig. 14). Some work is being done to improve the beef animals but the principles involved are the same as can be applied in breeding dairy animals.

In the United States of America, around the Gulf of Mexico cross-breeding of Zebu with standard European beef breeds for resistance to sub-tropical climatic condition has been a general practice. From one of these crosses has evolved the Santa Gertrudis in the King Ranch[1], Texas,

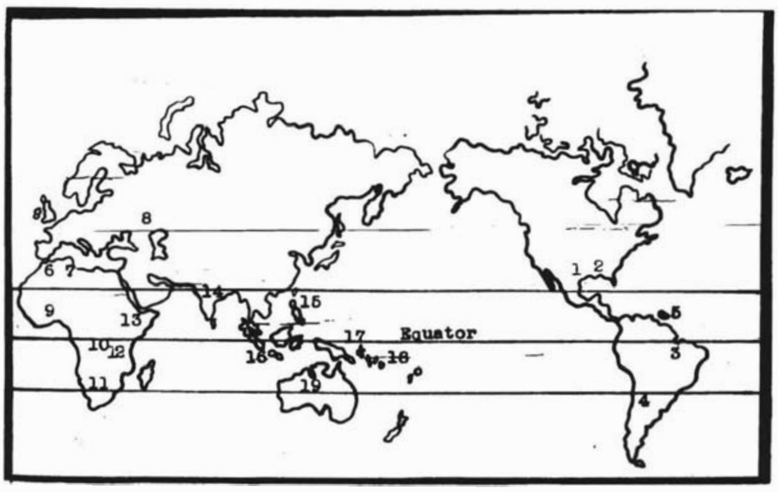


FIG. 14

Centres of Zebu cross-breeding.
The numbers correspond to those mentioned
in the text. (Adopted from Kelley[2]).

which has been already mentioned. In an experimental way the U.S. Department of Agriculture is developing a new type at the Iberia Livestock Experimental Farm, Jeanerette[2], Louisiana, where Rhoad(273)(275)(218) is stationed, by crossing Indian Zebu with Aberdeen Angus. Other crosses using the Africaner are also being made for purposes of comparison.

That dairy strains of the Indian Zebu cattle have not been used in the continental United States to improve the heat resisting ability of dairy cattle is partly owing to relatively milder temperature as compared with tropical Gulf Coast regions, and partly owing to the availability of Jerseys which, according to Freeborn et al(34) possess greater heat tolerance than some of the other breeds in the United States. Rhoad(218) found that the Jersey breed has a heat tolerance somewhat superior to ½ Indian Zebu - ½ Angus cattle. The predominance of Jersey cattle in the Southern States of America, as pointed out by Davidson(276), may be explained on this basis.

The failure of purebred Holstein-Friesian in the sub-tropical part of America resulting in lowered fertility due to "unfavourable weather" has been reported by Williams(264).

Rhoad(277) has discussed the problem of raising milk production in tropical America. Originally the native stock were Spanish and Portugese cattle imported in the early days of colonization. These were later crossed with the North European breeds and recently with the Indian Zebu. All grades of these crosses are present. The author has discussed three possible lines of improvement of the present dairy cattle population -

(a) Selection from original native cattle,

(b) Grading up by European bulls,

(c) Fixation of new type by selecting and breeding from among the existing crosses of native-Zebu and native-European cattle.

The last method has been advocated by the author for the improvement of dairy cattle in tropical America. A very recent report[278] shows that the Bureau of Dairy Industry are importing bulls and cows of Sindhi breed in an attempt to build up a new dairy breed for hot Southern Gulf area, by crossing these animals with the Jerseys in the same way as has been done in case of Santa Gertrudis. The results of this experiment would be of particular interest to the breeders in tropical countries. In Brazil and Argentina work is continuing to evolve cross-breds for the less favoured areas from Zebu-European crossing (Rhoad[218][273][275]). Hammond[263] and Metevier[279] have discussed the breeding work at Trinidad, Jamaica, particularly at the Government Stock Farms, where Zebus from India are being crossed with European dairy cattle, notably Friesians. Purebred and high grade Friesians have failed, as in other tropical countries, to stand the climate of Jamaica. The later policy has been to fix a dairy breed suited to local conditions by rigid selection among the hybrid animals.

Soyeur[280] reported from Morocco that the native cattle were first crossed with European cattle to increase milk production. The cross-bred animals became highly susceptible to disease and this made the importation and use of Zebu cattle desirable. The Zebus from Madagascar and Sudan were not satisfactory whereas the Indian Zebus gave excellent results. A "wise combination" of three types - indigenous, Zebu and European - has been aimed at.

From Tunis in North Africa it has been reported (Theiler[281]) that the production and immunity to tick-borne diseases were increased by mating local cattle with the Zebus from India.

8 From U.S.S.R. Zhuravok[282] reported experiments undertaken with the object of extablishing a useful dairy type of cattle resistant to piroplasmosis. Selected Zebu bulls were mated with high-yielding Red German cows. The first cross animals gave good yields and, although became infected with blood parasites, showed high resistance to the disease. Only a few (3 of 23 infected) died whereas the rate of mortality among Red German cattle under similar conditions was much higher.

9 Stewart[283] discussed the breeds of cattle of West Coast of Africa and their resistance to disease. The cattle are humpless with varying percentages of Zebu blood. He stated that the best cattle, located in the North-east of the Northern Territories, contains the highest concentration of Zebu blood. Smith[292] reported that from 1892 to 1907 all attempts to introduce European cattle into the Southern provinces of Nigeria had been a failure. Improvement now is being made by the use of 'hybrid' British and Zebu cattle bred in the high Kenya country.

10 Bouvier and Bouvier[284] reported that in the Belgian Congo, the most satisfactory breed is undoubtedly the Africaner, which is considered to be the only purebreed that does not degenerate after a few generations. The Hereford cannot stand the climate but the F_1 crosses with Africaner, which is a Zebu, are resistant to climate. The cross-bred type, though not yet fixed, has been claimed to be promising. The only dairy breed is Friesian, kept solely by Europeans.

11 In South Africa Schutte[285], Curson and Bisschop[286], Curson and Thornton[287], Bisschop[288][289] and Bonsma et al[44][88] have discussed the native breeds and the problem of improving them for beef purpose. They found that the British breeds, Herefords, Sussex, Aberdeen Angus

and Shorthorns degenerated when introduced into the South African territories. It has been stated that British breeds gave unsatisfactory results in those parts of the country with an average temperature higher than 68^{o} F during the coldest month. That the higher environmental temperature is the main factor responsible for the failure of the British breeds in South Africa has been conclusively shown by Bonsma et al. On the other hand indigenous Africaner breed is highly resistant to high temperature and has been developed into a standard beef breed. From further up the East African coast French[265][266] reported the attempts at[12] improving the native short-horned Zebu of Tanganyika by crossing with imported breeds from South Africa, India and Europe. He stated that grading up by European breeds, Ayrshire and Friesian, gave in the first cross animals much improved in size and productivity but higher grades broke down constitutionally and were disappointing in growth rate, body development and milk yield. This was not due to the less digestive efficiency of these animals because French[290] did not find any significant differences in the digestive powers of Zebu and high grade Ayrshires-Zebu cattle. The cause of the failure of these animals was found to be the high environmental temperature which impaired the temperature-regulating mechanism resulting in higher body temperatures and respiratory rates. The suitable breeding policy was stated to be either to select and breed from indigenous cattle or to grade them up with bulls of suitable Indian breed. Still further north, Tarantino[291][13], discussing animal industry in Italian Somaliland, stated that by judicious selection from among the native cattle an extremely hardy and resistant animal could be evolved which would be invaluable for agricultural work. He also stated that the milk yield of Somali cows is unsatisfactory and that Somali

Brown Swiss cross animals gave satisfactory yields. However, no further reports have been made about the adaptability of the cross-bred animals to the climate of the country.[14] The problem of breeding in India for increased milk production has been discussed by Kartha (293)(295); MacGuckin (296); Murari (297); Wright (13); Schneider (299) and Ware (10). India for centuries has had a very large population of Zebu cattle, the average production of which is very low. This led to the foundation, in the earlier days, of the Military Dairy Farms in order to get an adequate supply of wholesome milk for the troops. Friesian, Ayrshire, Shorthorn and Jersey cattle were imported and mated with native cattle. The failure of the European cattle in India has been mentioned before (cf. Adaptability). It was found that any admixture of European blood greater than 50%, made the cross breeds unsuited to the climatic conditions of India. MacGuckin stated that "cross-bred and grade cows are not so efficient in throwing off body heat. If they produce large quantities of milk during hot weather, their constitution or that of their progeny deteriorates." So the policy of improving milk production of the native cattle by grading up with the bulls of European breeds has been abandoned and the present policy has been to develop dairy strains by selecting and breeding from among the Indian breeds with high milking potentialities and great success has been attained in this respect. Sahiwal, Sindhi and Tharparker herds on the Government Dairy Farms have attained an average production of more than 7,000 lbs. of milk per lactation showing that pure Indian cattle when bred and managed properly can more than hold their own with European cattle in economy of production. Bulls of these improved strains are now being used to grade up the cattle in the villages. Recently herd books have been opened by the Central Government for

Sahiwal, Sindhi and Hariana breeds. The animals cannot be entered into the herd books unless they give certain minimum yields and satisfy certain conformations. Progress is being made in this direction (Indian Farming[15] (294)).

In the Phillipine Islands Manresa (274)(300)(301), Manresa and Erec (70) have observed that purebred animals, Friesians, Jerseys and Heredords, imported from temperate climates, are unsuited to the local environment. These workers have shown that not only the metabolic functions such as body temperature and respiration rate but also the blood units e.g. haemoglobin index of these animals, are adversely affected. They reported that a beef-draught breed is being developed in the College of Agriculture from an admixture of native cattle, Indian Zebus and Herefords. This new breed has been named Phillamin. In a similar way the Department of Agriculture is also working on a dairy breed for the Phillipines. The difficulties associated with this attempt of evolving and fixing a new breed from native-European-Zebu crossing have been realized and discussed by these workers. Among the Pacific Islands, the Netherland East Indies,[16] New Guinea[17] and the Solomon Islands,[18] it has been found that the cattle with Zebu blood do better than European breeds.[19]

In the tropical north Australia (Kelley (2)(11)) British-bred beef breeds, Hereford, Shorthorn, are not so suited to the environment as the Zebus. The cross-bred animals grow much better and produce heavier carcasses of better quality. The cross-bred animals show great resistanc to high atmospheric temperature, drought and tick infestation and it has been stated that the mortality rate among these animals is lower than among British breeds. The present policy has been to breed and rear Zebu-British cross-bred animals and maintain the Zebu blood between 25 and 50% in the cross animals.

All this evidence shows the superiority of the Zebus or cattle with Zebu blood over the European cattle under the conditions of tropical and sub-tropical temperatures. The primary cause of the failure of European cattle in the tropics is the inferiority of their heat regulating mechanism and inability to maintain body temperature at normal level at high atmospheric temperatures. Therefore the policy of grading up tropical cattle with the bulls of European dairy breeds is a wrong one. The breeding policy for improving the dairy cattle in a tropical country should be either to select and breed from indigenous cattle with high milking potentialities, if any, or to grade up the native cattle with bulls of a suitable tropical dairy breed possessing high milking capacity, or fix and evolve a new dairy breed by crossing the native or some other suitable Zebu cattle with a suitable European dairy breed followed by judicious inbreeding. The first two methods, if possible are easier and less expensive than, and preferable to the last method.

VIII

SUMMARY AND CONCLUSIONS.

1. India possesses a large cattle population - about 200 million cattle. Indian cattle are mostly dual purpose (milk and draught) and the average annual production per cow is very low - only 487 lbs. of milk. India's total milk production has been estimated at 6,400 million gallons of milk. The per capita consumption of milk per day - milk products converted to milk - is miserably low, only about 7 ozs. Therefore for the nutrition of the Indian people who subsist mainly on a vegetarian diet, there is a great need for increased production and consumption of milk. It has been estimated that the per capita consumption of milk per day should be increased to 15 ozs. and so the total milk production in India should be increased twofold. Problems of cattle improvement in India are manifold - religo-social, feeding, breeding, managemental and also climatic.

2. Temperature, particularly high temperature, has a great influence on the performance of dairy cattle. High temperature adversely affects the physiological functions of a dairy cow - body temperature rises, respiration rate increases, haemoglobin content of blood tends to fall, metabolism, food consumption and utilization, grazing performance, functions of endocrine glands, growth, reproduction, production and disease resistance of the animal are seriously affected.

3. The detrimental effect of high temperature on dairy cattle can be related to the phenomenon of regulation of body temperature and the efficiency of a dairy cow in disposing of surplus body heat. In addition to the mechanical heat production subsidiary to the maintenance of body temperature, blood circulatioh, respiration and other physiological and metabolic functions, dairy cattle produce a huge amount of extra heat due to feeding of roughages (S.D.A. and fermentation heat) and also absorb large amount

of solar heat on bright sunny days. In order to maintain body temperature at normal, this surplus heat must be dissipated. Under the conditions of low environmental temperatures, however, the extra heat due to feeding can be conveniently utilized by the cow to maintain body temperature without increasing metabolism solely for this purpose. This is why a well fed dairy cow can withstand temperature as low as or lower than freezing point and why her performance is not appreciably affected at reasonably low temperatures.

On the other hand, the disposal of surplus body heat is a serious problem to the dairy cow at the high environmental temperatures. The cow is a non-sweating or slightly sweating animal and all the surplus heat is to be dissipated by means of radiation, conduction and convection processes and evaporation from the lungs. As the environmental temperature approaches body temperature, all the burden falls upon respiration. At still higher temperatures heat is absorbed by the body from the environment - radiation, conduction and convection are reversible processes - and respiration alone cannot cope with the heat production and the animal reaches a state of hyperthermic feverish condition. The upper critical temperature for a dairy cow lies between 70° and $80^{\circ}F$ depending on the breed. Above this critical temperature her vital functions such as body temperature and respiration rate are impaired, she consumes less food in order to minimise heat increment due to feeding and suffers from what can be called "physiological undernutrition." As a result all the important physiological functions and growth, reproduction, production, that is, the performance of the dairy cow, are seriously affected.

4. The tropical cattle, known as the Zebus or Bos Indicus, are genetically different from the Bos Taurus or European cattle and, unlike the latter, are highly resistant to tropical temperatures. Due to their possessing numerous

sweat glands, thick -pigmented skin, short-haired coat and greater body surface per unit liveweight, they can dissipate surplus body heat very efficiently and are least affected by high temperatures whereas the European cattle are highly vulnerable.

5. The inefficiency of heat disposal of the European cattle at high environmental temperatures also explains why the European dairy breeds when imported into the tropical countries fail to adapt themselves to tropical climate, become highly susceptible to tropical diseases and degenerate in type and production.

6. The past attempts to improve dairy production in tropical countries by grading up the native cattle with European breeds have been futile. In breeding dairy cattle for the tropics, the object should be to combine high heat resistance and high milking capacity in the animals and this can be achieved either

(a) by developing dairy strains through selecting and breeding from amongst the native Zebu cattle or

(b) by evolving a new breed through crossing the native cattle with a suitable European breed followed by interbreeding of the cross-bred animals in combination with rigid selection and thus fixing the high heat tolerance and high milking ability in the offspring or

(c) by grading up native cattle with the bulls of a high yielding Zebu breed.

The practicability of these methods and the difficulties therein have been discussed.

7. The great influence of high temperature on the performance of dairy cattle has hardly been realized in India and the early attempts to increase India's dairy production by importing European dairy breeds have failed. The results obtained on Government Dairy Farms in recent years have amply shown that certain breeds of Indian cattle e.g. SAHIWAL, SIND

THARPARKER and a few others, are endowed with potentialities for high milk production. In breeding dairy cattle in India in order to increase dairy production which is so vitally important for balanced nutrition of the Indian people, there is no need to import European dairy cattle either for grading up purposes or for creating new breeds from Zebu-European crossing. In consideration of the great influence of temperature on the performance of dairy cattle it appears that the most practical and wise course will be to select and breed from Indian cattle and develop dairy strains capable of high production and suited to different parts of India. Along with breeding, feeding and managemental conditions must be improved. If properly bred, fed and managed Indian dairy cattle will in no way be inferior to the specialized European dairy breeds and the target of India's milk production - increasing it twofold - will not be at all difficult to reach.

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