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The Signifiance of Meteorology in Animal Production

by

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ABSTRACT.- The production of meat, milk and eggs is highest and occurs at a maximal efficiency if the meteorological elements are within a certain range (zone of indifference). Outside this range the animal has to combat meteorological stress. This requires extra energy, so that less energy is available for productive processes. It is therefore important to find out at which levels the various meteorological elements become stressful to the animal organism. This study has to take into consideration the diversity of domestic animals, both with regard to structural features and functional traits. Responses of various categories of domestic animals to the following potentially stress producing meteorological conditions are briefly reviewed: cold, heat, solar radiation, high altitude and indoor environment. Knowledge so derived can be applied either by adapting the animal to the environment by breeding and selection, or by adapting the environment to the animal by technical and managerial means. Some suggestions are made for future considerations in the field of biometeorology of domestic animals.

THE METEOROLOGICAL COMPLEX

The meteorological elements constitute a complex system which acts upon the animal body. Jointly they may be expressed as climate, i.e. as long term average conditions, or as weather, i.e. as short term fluctuations. Furthermore, they may affect the animal out of doors or inside animal houses. The meteorological elements can influence the organism singly, or in various combinations, e.g. low ambient temperature + high air movement (cold), or high ambient temperature + high air humidity + solar radiation (heat).

Attempts have been made to condense two or more meteorological elements into a biometeorological index. Examples are "cooling power" and "wind chill". It is important, however, to recognise that the effect of a given meteorological element may vary quantitatively in different species. When, for instance, wet- and dry bulb temperature are combined to an index of heat stress, the corresponding weighting factors differ, depending on the species involved. As evident from Table 1, wet bulb temperature is about six times more effective than dry bulb temperature in causing heat stress in man, but only about half as effective in the young pig. This is due to the fact that man is a profusely sweating, the pig a non sweating species.

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TABLE 1. Relative importance of wet bulb and dry bulb temperature (°C) in causing heat stress in various species. (From Bianca, 1968)

	Weighting factor (%)		
	Wet bulb temperature	Dry bulb temperature	Wet bulb temperature / Dry bulb temperature
Man (Provins et al., 1962)	85	15	5.7
Ox (Bianca, 1962)	65	35	1.9
Young pig (Ingram, 1965)	35	65	0.5

THE ANIMAL COMPLEX

Wild animals have been adapted to their meteorological environment through natural selection. They also have the possibility of seeking favourable microclimates within a stressful macroclimate. Meteorological problems therefore normally do not arise with them.

By contrast, domestic animals have been selected and bred by man for productive traits, and sometimes even for fancy points. In addition, domestic animals may be transferred from one meteorological environment to another, and the chance of escaping from a stressful environment into a less stressful one is usually restricted. Thus, domestic animals may be poorly adapted to their meteorological environment.

If domestic animals become more and more adapted to the specialised economic demands of man, the genetic pool will diminish, so that eventually strains, breeds and species do not have sufficient genetic resources to cope successfully with adverse meteorological conditions existing for instance in developing countries. This trend could be counteracted by preserving populations of animals that possess high potentials for tolerating stressful environments.

Partly as a result of the process of domestication, domestic animals show a great diversity in structural features (size, shape, hair coat) as well as in functional traits (metabolic rate, homeostatic mechanisms). This diversity is further augmented by management and nutrition. Sheering of sheep, for instance, raises the animal's lower critical temperature from about 0°C to almost 30°C, thereby depressing its tolerance to cold. A high level of feeding (in a cow with a genetic capacity for high milk production) leads to an increase in metabolic rate. A cow with a milk yield of 10 kg/day produces approximately 17'000 kcal, while a cow with a milk yield of 50 kg/day produces about 36'000 kcal. This represents an extra heat load, which is difficult to dissipate in a hot environment. Another factor is age. A newly born piglet has a lower critical temperature of 33°C, an adult pig one approaching freezing point.

There are, thus, numerous categories of domestic animals which vary greatly in their meteorological requirements. This poses special problems, in particular when animals of different categories have to be kept together, as for instance the sow and its piglets.

THE IMPACT OF METEOROLOGICAL ELEMENTS ON DOMESTIC ANIMALS

The impact of meteorological elements on domestic animals can be detrimental or beneficial. For most meteorological elements there is a range of indifference, i.e. a zone within which compensatory responses by the organism are absent. If the meteorological conditions move outside this range, the animal gets stressed and begins to activate its defence mechanisms. This is exemplified in Fig. 1 for environmental temperature as a stressor.

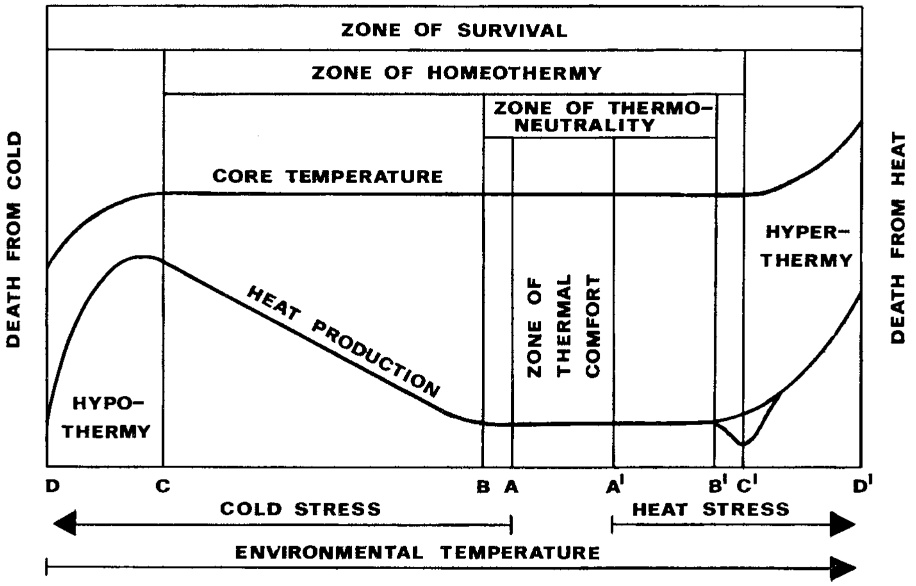

Fig. 1. Critical temperatures and zones (From Bianca, 1968).

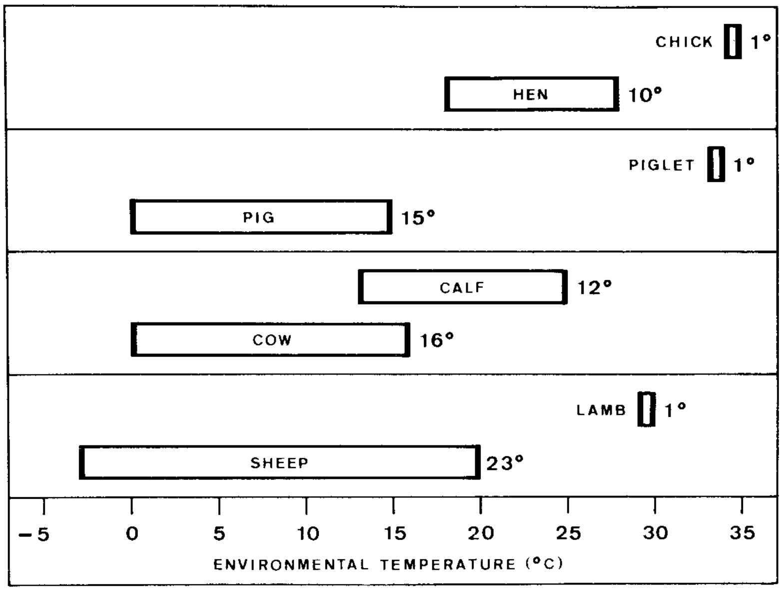

Fig. 2. Zones of thermal indifference (From Bianca, 1971).

Figure 2 gives an indication of the zones of thermal indifference for four species of farm animals, both, in the newborn and the adult state. The diagram shows a striking age difference. The young animal has a narrow zone at a relatively high temperature, the adult animal has a broad zone at a relatively low temperature. This means that the young, compared with the adult animal of the same species, has higher thermal requirements and that in it cold- and heat stress are separated from one another by only a narrow band of environmental temperature. The temperature zones given in Fig. 2 refer to indoor conditions. Various modifying factors may shift these zones to lower or higher temperatures.

A stressful meteorological environment has often to be accepted in animal production. The explosion of human population requires that animal protein be produced not only under favourable but also under the unfavourable meteorological conditions prevailing in tropical, polar and high altitude regions. Here the problem arises of finding out animals best suited for life under such conditions.

Beneficial effects under certain circumstances, may arise from the impact of radiation on the animals, as will be shown in chapter on "solar radiation".

Under field conditions, where a multitude of factors is operating simultaneously, it is important to make a distinction between direct and indirect effects of the meteorological environment on the animals. The milk yield of a cow on a tropical pasture, for instance, may be low because of the thermal load imposed on the animal, and/or because of the low density of plants on the pasture, requiring much walking, the poor quality of feed, inadequate water supply, irritating insects and disease producing microorganisms. Yet, for taking practical measures for improving milk yield under these conditions, it is essential to know which of the factors are mainly responsible for the low milk yield.

The impact of the meteorological environment on the animal can vary in magnitude. When expressed in terms of animal response, one may differentiate between various degrees of strain produced in the organism. Taking heat stress as an example, the following categories may be arbitrarily distinguished:

(a) Thermal indifference: This has been described above.
(b) Mild heat: The thermoregulatory mechanisms of the body can completely compensate for the extra heat load, so that body temperature remains normal.
(c) Moderate heat: The thermoregulatory mechanisms work at a higher intensity; body temperature can be stabilized, but at an elevated level.
(d) Severe heat: The thermoregulatory mechanisms are overtaxed; body temperature rises continuously and secondary effects may occur. This leads, eventually, to exhaustion and death.

For different animals as well as for different conditions in a given animal (advancing age, level of nutrition, state of acclimatization etc.) these categories occur at different intensities of the meteorological elements. This should be born in mind in comparative studies.

Whenever an animal's homeostatic mechanisms are activated, extra energy is expended in the process. The energy so expended is no longer available for productive processes. Thus, the more the organism combats meteorological stress, the less is its capacity for producing meat, milk and eggs.

After these general considerations on the impact of the meteorological environment on the animal, specific problems - cold, heat, solar radiation, altitude and indoor environment - will be discussed.

COLD PROBLEMS

In livestock, cold normally represents a smaller problem than heat. In the extreme this is reflected in lethal body temperatures at low and high environmental temperatures. The difference between normal and lethal body temperature is of the order of 15 - 25°C in the cold, but of only about 3 - 6°C in the heat. Moreover, those factors which are desirable in livestock, namely a high rate of growth, high yields of milk and eggs, and the state of pregnancy, are all associated with a high metabolic rate and hence with a high heat production, which is conducive to a high tolerance to cold.

A cold problem arises when the ambient temperature falls below the lower critical temperature of the animal. The lower critical temperature is defined as the environmental temperature below which the animal has to increase its heat production to prevent its body temperature from falling. An increase in heat production means that the animal consumes more feed and that the extra energy contained in it is used for heating the body and not for producing milk and meat. As shown in Table 2, the lower critical temperature, the "starting point" on the "cold scale", varies considerably between different categories of animals: from around freezing point to 34°C.

TABLE 2. Lower critical temperatures (°C) and rank order of increasing thermal demands.

	°C	rank
Calf	13	4
Cow (dry)	5	3
Cow (high lactating)	0	2
Piglet (newborn)	33	9
Pig	0	2
Lam (newborn)	29	8
Sheep	-3	1
Sheep (shorn)	28	7
Rabbit	15	5
Chick (first week)	34	10
Hen	18	6

There is a pronounced difference between the young and the adult animal, especially in species of small body size. The young not only has a higher value of the lower critical temperature, but it also has the ability to increase its heat production very rapidly and to attain a high summit metabolism. A high metabolic rate, however, requires much energy. The total energy reserve of a lamb, for instance, is only 40-1000 kcal (Alexander, 1962a). If the cold exposed lamb does not suck successfully, its energy reserves are soon exhausted by the metabolic rate which in the cold may be as high as 60 kcal/hr (Alexander, 1962b). Good prenatal nutrition enhances the survival time of lambs in a cold environment.

There is the possibility of depressing an animal's lower critical temperature, thereby improving its cold tolerance. This is effected by an increase in thermal insulation or by an increase in heat production. In cattle, kept out of doors during winter, an increase in insulation, mainly brought about by changes in the hair coat, can lead to a critical temperature as low as -30°C (seasonal acclimatization). A rise in heat production can, within limits, be effected by augmenting the level of feeding. The lower critical temperatures of oxen was 18°C when the animals were fasted, and -1°C when fully fed (Blaxter, 1965).

The concept of the lower critical temperature is based on ambient temperature alone. However, the "coldness" of an environment depends also on air movement and rain. The most stressful combination is that of low temperature, high wind and rain, as shown in Table 3.

TABLE 3. Effect of wind and rain (at an ambient temperature of 7.4°C) on the heat production of sheep (length of fleece 14 mm). (From Blaxter, 1965)

Environmental conditions	Heat production kcal/(m^2 . day)
Dry, no wind	1810
Dry, wind 4.47 m/s	2383
Rain, no wind	2914
Rain and wind 4.47 m/s	3363

Under such conditions shearing of sheep may lead to animal losses as high as 24% (Hutchinson, 1966). But it has been shown that the mortality of sheep exposed to cold wind can be reduced by using a special shearing head which leaves approximately 1,2 cm length of wool on the animals thereby providing a useful minimal thermal insulation (Hutchinson, Bennett and Wodzicka Tomaszewska, 1960).

HEAT PROBLEMS

Heat refers to those meteorological elements which either interfere with the dissipation of body heat to the environment (high ambient temperature and humidity) or which impose an external heat load on the animal (solar radiation).

The more heat an animal produces internally by its metabolism, the less is its capacity for tolerating external heat. There is thus a basic incompatibility between a high level of production (involving a high production of waste heat) and a high tolerance to heat. There are, however, certain means, by which optimal compromises can be achieved. (See chapter on applications).

In Fig. 2, the upper limit of the zone of thermal indifference (right end of the horizontal bar) may be termed "upper critical temperature". This is the temperature at which evaporation (from the skin and/or the respiratory tract) begins to rise. At this temperature the animal begins to be stressed by heat. A simplified version of what happens to a cow with increasing ambient temperature, is shown in Fig. 3.

In this connection, appetite should be mentioned as a mechanism of thermoregulation in a hot environment. When environmental temperature rises above a certain level, appetite begins to decline. As a result, the caloric intake decreases, heat production diminishes and body temperature is more easily maintained. The heat induced fall in feed intake is advantageous to the animal but its consequences mean an economical loss to the farmer. As seen in Fig. 4 feed intake in lactating cows begins to fall in the temperature range 20-25°C. In nonlactating cows this occurs at higher temperatures because of their lower heat production.

Heat problems may arise in animals that are transferred from the temperate zone to tropical areas, and, to a lesser degree, also under summer conditions in the temperate zone.

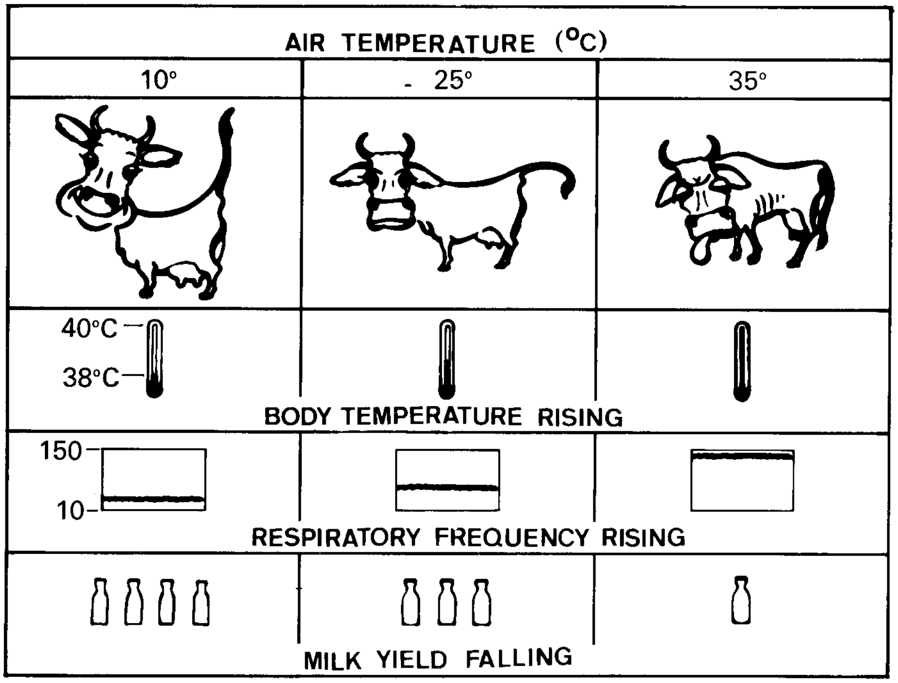

Fig. 3. The dairy cow in a hot environment.

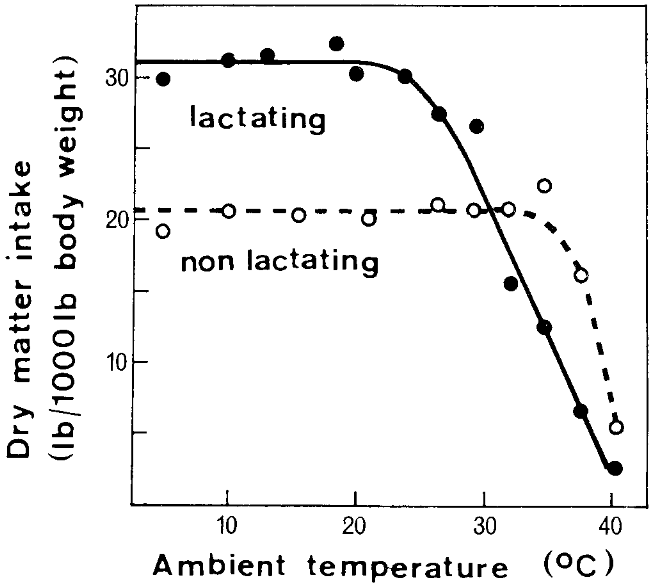

Fig. 4. Decline in feed intake of lactating and non lactating cattle with rising environmental temperature (From Winchester and Morris, 1956).

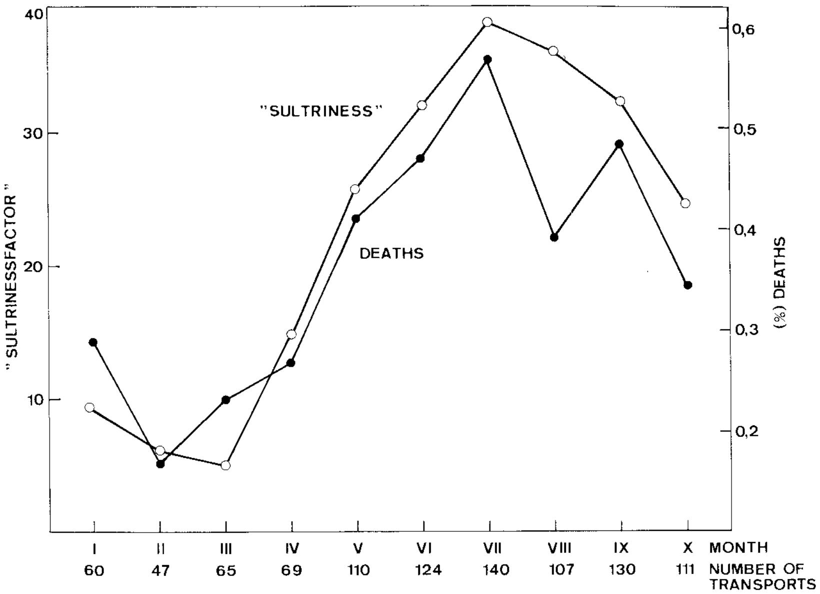

Fig. 5. Deaths of pigs during transport in hot weather in relation to the "sultriness factor". (From von Mickwitz et al., 1971)

A rather special problem can be created by the transportation of animals, especially of pigs, during hot weather. The animals are subjected to high temperature and humidity, they may receive a radiative heat load from sun heated roofs of metal containers. Further more, the animals, owing to crowding and emotional excitement, produce extra heat and moisture, which aggravate the microclimate. Under such conditions animals can die, particularly from circulatory failure. Mickwitz et al. (1971) estimate that in Germany 1, 2% of the pigs die as a result of transportation to the slaughter house, leading to an economic loss of the order of 45 million DM per year. As may be seen from Fig. 5, the number of deaths from transportation increases with increasing sultriness of the atmosphere. Transportation losses can be reduced by avoiding extrem weather conditions. This can best be achieved by a close cooperation with the weatherforcast service.

SOLAR RADIATION

In the tropics and deserts solar radiation may reach intensities as high as 1000 kcal/(m^2.h) (Macfarlane, 1968). The infrared rays place a heavy heat burden on the animals. Under extreme conditions the solar heat load impinging on the animal can exceed the heat generated in metabolism by a factor of five.

To what extent the solar heat enters the body, depends on the hair coat, which acts as a first line of defence. Reflection of solar radiation is highest from a smooth hair coat, consisting of short, thick, medullated hairs. In sheep, a fleece, having a depth of at least 2 cm, provides an efficient barrier against the penetration of solar heat to the skin (Macfarlane, 1968). Removal of the fleece under such conditions greatly increases the animal's heat strain.

Under a high external heat load the small animal has the disadvantage of possessing a relatively large (heat absorbing) surface and a relatively small (heat storing) body mass. Kleiber (1962) made the assumption, which seems realistic with respect to the daily heat load in many hot regions of the world, that an animal over a period of 6 hours would receive an influx of heat from its environment equivalent to 250 kcal/m^2. If all this heat were stored, the storage in differently sized but otherwise comparable animals would lead to the increases in body temperature shown in Table 4.

TABLE 4. Heat storage and estimated increase in body temperature produced by an influx of heat, equivalent to 2.5 kcal/dm^2, over a period of 6 hours, in animals of different sizes. (From Kleiber, 1962)

Body weight (kg)	$\frac{\text{Body surface}}{\text{Body heat capacity}}$ * $\frac{dm^2}{kcal/^{o}C}$	Increase in body temperature (^{o}C)
1	12.5	31.4
10	5.8	14.5
100	2.7	6.7
1,000	1.2	3.1

*) $\frac{10 \text{ x } W^{2/3}}{0.81 \text{ } W}$

It is evident, that the rise in body temperature produced by a standard heat load increases with decreasing body size. The body temperature of a 1 kg piglet would rise about 6 times more than that of a 300 kg pig. This means that a short periodical external heat load, can be better "buffered" by the large than by the small animal.

A special role is played by ultraviolet radiation. Irradiation of the skin with ultraviolett rays has an anti-rachitic effect, by converting 7-dehydrocholesterin into vitamin D3. It is probable that this beneficial action can take place only in those parts of the body which have non or only little hair covering, since a normal cattle hair coat shields against ultraviolet (Bianca and Wegmann, 1974).

Deleterious effects of ultraviolet radiation are sunburn and eye cancer. Both occur predominantly in animals with unpigmented skin. Hereford cattle, which have white heads, are particularly prone to develop eye cancer. However, a pigmented ring around the eys and pigmented eye lids seem to offer adequate protection against eye cancer (Bonsma, 1949). In regions with intensive solar radiation, therefore, Hereford cattle having brown "spectacles" are given preference in selection (Fig. 6).

Finally, radiation, or more specifically, the day length (photoperiod) plays a role in reproduction. In saisonally reproducing species light regulates the breeding cycle. In sheep from the northern temperate zone breeding occurs in autumn, that is, under conditions of decreasing day length. In the horse breeding tends to occur in spring, that is, under conditions of increasing day length. With gestation periods of 5 and 11 months, respectively, birth of the young in both species falls into spring, where conditions are optimal for the development of the young. When transferring seasonally breeding animals from one hemisphere to the other, it is important, therefore, to make the transfer at the right time of the year in order to ensure optimal fertility of the animals in the new environment.

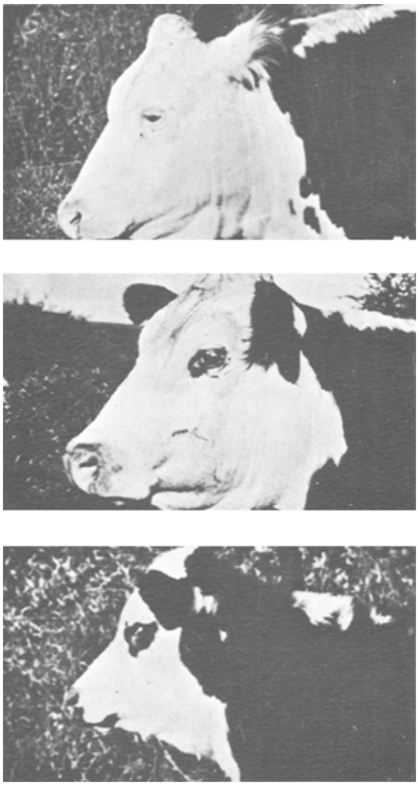

Fig. 6. Hereford cattle and pigmentation around the eye. Top: no pigment; middle: small, interrupted ring of pigment; bottom: wide ring of pigment. (From Bonsma, 1949)

In the chicken, a species particularly sensitive to light, man manipulates the photoperiod, in order to improve the development of chicks and the production of eggs. Since in many countries this practice is applied on a large scale basis, it has some economical importance.

HIGH ALTITUDE

In various regions of the world, notably in the Andes, the Himalayas and the Rocky Mountains, numerous domestic animals are resident at or have been introduced to altitudes of up to 4500 m. The high altitude environment constitutes a complex multifactorial system, including hypoxia, coldness and dryness of the air, intensive solar radiation, deficient feed supply, and a hilly landform requiring extra energy for walking.

Under these conditions, genetically and/or physiologically unadapted animals show deteriorative changes, which have been "studied particularly in cattle and termed "chronic mountain sickness" or "brisket disease". The most overt clinical manifestations of the disease are weakness, unthriftiness, ruffled up hair, oedema in the region of the brisket, venous pulse, diarrhea, coughing, laboured breathing and cyanosis of mucous membranes. Affected animals are unproductive and eventually may even die.

The disease is basically caused by hypoxia, the chain of events being: hypoxia-vasoconstriction and muscular hypertrophy of small lung blood vessels, increase in pulmonary vascular resistance to blood flow, rise in pulmonary artery pressure, hypertrophy of the right side of the heart, and congestive heart failure with concomitant pathological changes.

Pulmonary hypertension can be reduced by moving affected animals to lower altitudes or by letting them breathe oxygen, both procedures pointing to hypoxia as the main aethiological factor.

It has been shown, however, that there are various predisposing factors which cause the disease to break out already at moderate altitude: cold and physical exercise and a high metabolic rate enhance the animal's requirements for oxygen, thereby acting as amplifiers to hypoxia. The experience is that the incidence of chronic mountain sickness in cattle is higher in winter than in summer. Another factor is poor nutrition which lowers the general resistance of the animals.

In contrast to hypoxia, which has to be accepted as an unescapable influence, the predisposing factors mentioned can be brought under control, at least partically. In this way the deleterious effects of hypoxia can be mitigated, allowing animal production to be extended to higher altitudes.

THE INDOOR ENVIRONMENT

Domestic animals are housed both to protect them against climatic extremes and to facilitate their management. In recent years animal production has more and more assumed the character of a high intensity "bio-industry". This is particularly true of the production of poultry, eggs, porc and veal. The climatic conditions prevailing in animal houses are of special importance for the following reasons:

(1) The genetic capacity of farm animals for producing high yields, as well as the general level of nutrition has in the industrialised countries reached a relatively high standard, so that in the production process a non-optimal indoor climate can easily become the minimum factor of the environment.

(2) High yielding animals, as well as animals that have been specially developped to satisfy man's taste, for instance the lean pig and the anaemic calf, tend to have specialized climatic requirements.

(3) Any ill effect of an unsuitable indoor climate will build up in the organism, since the animals spend their whole lives within this climate.

(4) Owing to the great number of animals kept together in one unit, a non-optimal indoor climate may lead to a large scale economic loss. Under extrem conditions, e.g. when a ventilation system breaks down, thousands of animals can be killed.

The indoor environment represents a modified outdoor environment (some elements being filtered or suppressed), supplemented by direct and indirect products of animal metabolism, in particular heat, moisture, CO_2, NH_3 and H_2S. An overall picture of the indoor environment is given in Fig. 7.

A 600 kg cow yielding 30 kg of milk per day, produces in 24 hours around 28'000 kcal of heat, 15 kg of water vapour and 5000 l of carbon dioxide. All these compounds, as well as dust particles, have to be prevented from accumulating to concentrations detrimental to animal health and production by an appropriate ventilation of the building. In a cold macroenvironment, the heat for warming the building, for economic reasons, is derived chiefly from the animals. The rate of ventilation, therefore, must be an optimal compromise between a clean but cold and a warm but polluted atmosphera. Where this compromise lies depends on the heat requirements and on the tolerance levels of the animals to the various gaseous compounds.

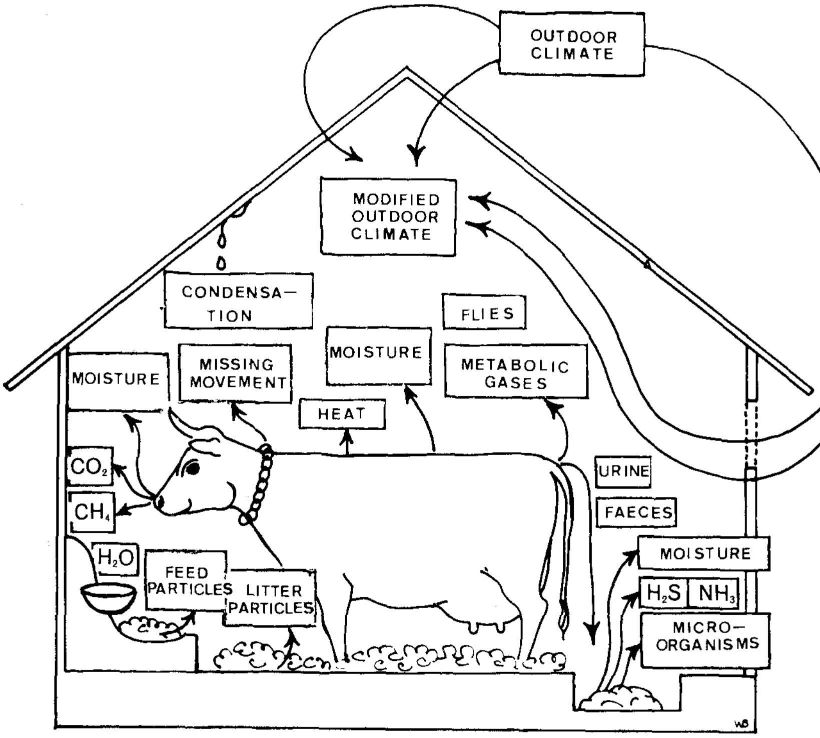

Fig. 7. The indoor environment of cattle houses.

The heat requirements of various categories of housed animals are fairly well known. They are indicated by the zones of thermal indifference, some of which are shown in Fig. 2. Recommendations on the maximally tolerable gas-concentrations are still controversial. This is due, in part, to the complexity of the situation under practical conditions, and to the paucity of longterm controlled experiments.

A special feature of most indoor environments is the low level of lighting which in conjunction with lack of physical exercise and of social contacts of housed animals, may lead to a depression in sexual functions, and fertility. Light plays an important role for animals kept for breeding, but is less important for animals kept for growth and fattening. In the design and building of animal houses, it is desirable to have a close cooperation between the farmer, the architect and the biometeorologist.

APPLICATIONS

Animal biometeorology deals with the relationships between the animal and its meteorological environment. It involves in particular the study of animal reactions, qualitatively as well as quantitatively, to stressful meteorological conditions. Such studies are performed in the field as well as in climatic rooms. These approaches are complementary. Indeed, many problems are best solved by passing them from the field, where they are first observed, to the laboratory for analysis, and back again to the field for synthesis.

Once the most important causal relationships between the animal and its meteorological environment have been established, there are two principal ways in which knowledge gained can be applied:

(1) the adaptation of the animal to the meteorological environment, and

(2) the adaptation of the meteorological environment to the animal.

The first is a biological, the second a technical problem.

ADAPTATION OF THE ANIMAL TO THE METEOROLOGICAL ENVIRONMENT

Here the presence of a stressful meteorological situation is accepted and attempts are made to provide animals which can cope with it relatively well. This is done by breeding and selection.

For tropical conditions the usual way is to combine European breeds, contributing a high production capacity, with indigenous breeds, contributing tolerance to heat and other adverse environmental conditions. Table 5 shows five breeds of beef cattle designed for life in hot areas. Normally, the genetic portion contributed by the indigenous partner is increased with increasing severity of the environmental conditions. An instructive example of a 'tailor-made' breed is the Santa Gertrudis, which has been evolved in the semi-arid zone of Texas and which has spred from there all over the world.

TABLE 5. Breeds of beef cattle evolved for hot regions

Name	Constituting breeds and their numerical genetic contributions
Santa Gertrudis	5/8 Shorthorn x 3/8 Brahman *
Brangus	5/8 Angus x 3/8 Brahman
Charbray	3/4 Charolais x 1/4 Brahman
Beefmaster	1/4 Shorthorn x 1/4 Hereford x 1/2 Brahman
Bonsmara	3/8 Shorthorn x 5/8 Afrikaner

*) Brahman = American Zebu.

In certain areas it has been shown that it is possible to build up heat tolerant herds of cattle also from temperate climate stock by applying rigorous selection combined with acclimatization.

ADAPTATION OF THE METEOROLOGICAL ENVIRONMENT TO THE ANIMAL

Here the stressful meteorological situation is counteracted by building, engineering and managerial means. The reduction of the stress is mostly achieved by reducing the impact of meteorological elements, or by eliminating them completely, thereby improving the microclimate of the animals. The indoor environment, discussed earlier, represents such a modification with respect to cold protection.

In hot regions numerous devices are in use. The most obvious among them is a sunroof, which shields the animals from direct solar radiation without interfering substantially with heat loss. In this way the radiative heat load on the animal may be reduced by about one third as shown for the pig in Fig. 8. A reduced radiative heat load increases body weight gain and feed conversion. As indicated by Table 6, the magnitude of the increase depends on the type of sunroof used.

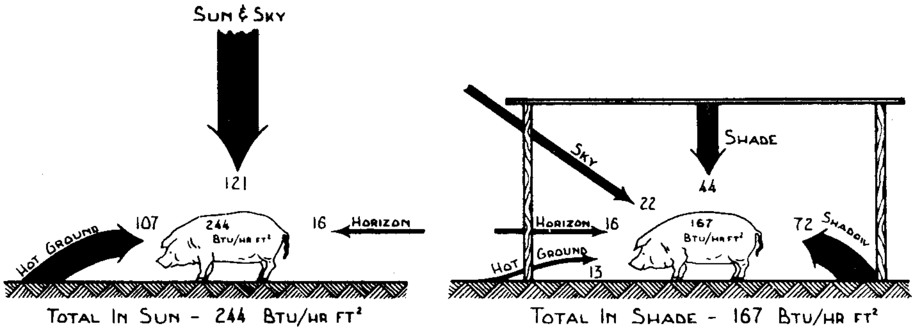

Fig. 8. Radiation heat loads (Btu/hr per sq ft of animal surface) received by shaded and unshaded pigs on a cloudless summer day in El Centro, California. (From Bond, Kelly and Ittner, 1954)

TABLE 6. Comparison of weight gains of Hereford steers using three different types of sun roof material. (From Ittner, Bond and Kelly, 1958)

Type of sun roof	Number of steers	Average gain (lb/day)*	Feed per 1000 lb gain (lb)
Galvanized iron	5	0.69	1230
Aluminium and burlap	6	0.80	1266
Hay and galvanized iron	5	0.89	1091

*) 1 lb = 0.45 kg

Another device is cooling animals by increasing air movement with the aid of a ventilator. In the Imperial Valley, a ventilator-generated air movement of 1.65 m/s, over a period of 70 days, caused in beef cattle additional daily gains of 0.35 kg per animal. At the same time the feed required per 50 kg of gain decreased from 577 to 430 kg (Bond, Kelly and Ittner, 1957).

Further improvements of animal comfort and production can be achieved by cooling the drinking water, by using thin cable rather than wood as fencing material, by seeking for cattle pens the vicinity of growing crops, where air temperature is lower than over bare ground, by allowing the animals exposure to the north sky, and by offering a diet with a low content of fibre (thus cutting down the high "heat increment" of fibre). Showers to wet the animals are useful, but only if there is sufficient air movement. In closed buildings, showers augment the humidity of the air, so that evaporative cooling from the animal's surface is reduced.

CONSIDERATIONS FOR THE FUTURE

Although in the past much knowledge has accumulated in the field of biometeorology of domestic animals, there still remain problems which should be given further consideration.

Climatic indices, as a rule, have been devised for man. As indicated in the first chapter, there may be a need for modifying them to suit various species of farm animals. The "wet-bulb-globe-temperature" index (WBGT, see Leithead and Lind, 1964), for instance, a heat stress index devised to include also the impact of solar radiation, is calculated according to the weighted expression:

$$\mathrm{WBGT} = 0.7\ \text{wet bulb temperature} + 0.2\ \text{globe temperature} + 0.1\ \text{dry bulb temperature}$$

For use in various animal species these weighting factors would have to be re-examined and probably modified, to make allowance for the principal channel of evaporative heat loss (panting or sweating) and for the thickness, texture and colour of the hair coat, all of which vary considerably in various categories of domestic animals.

The plotting in a single graph of mean monthly temperatures and humidities prevailing in a given area, the "climogramme", has been used in the past (Wright, 1954). Fig. 9 gives an example of a climogramme which includes also comparative figures for animal houses. In view of the introduction of farm animals from temperate to hot climates it seems desirable to make more use of this technique by constructing climogrammes of specific areas intended for exportation of livestock. There may be also a case for modifying and refining climogrammes by including other meteorological variables.

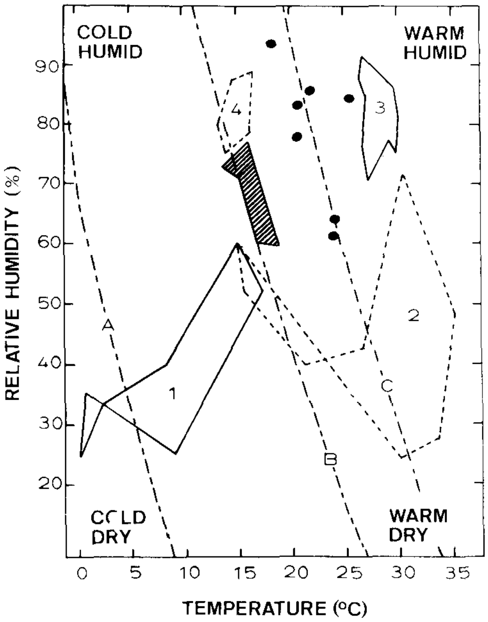

Fig. 9. Climogramme. Zone 1: Lhasa in Tibet. Zone 2: Delhi in India. Zone 3: Cochin in South India. Zone 4: Nuwera Eliya in Ceylon. Hatched zone: average values in a stable in the Netherlands. Black circles: maximal values in the stable. Area between the lines A and B: zone of "thermal comfort" of cattle (Kibler and Brody, 1953). Line C: upper limit of human comfort (from Oosterlee, 1958).

Weather forecast, although having its main agricultural application in crop husbandry, can play a useful role also in the transport of animals in hot or cold weather. An "early warning system" could be of help for reducing animal losses. As indicated in chapter "heat problems", a hot weather forecast should in the first place include a properly weighted combination of temperature and humidity. In the USA a "Livestock Weather Safety Index" is in use which, for practical purposes, is expressed in terms of the categories "alert", "danger", and "emergency", the last two categories indicating expected transport losses of 25 and 45%, respectively.

Another problem concerns the construction of animal houses. They must offer optimal meteorological conditions for the animals and must be relatively inexpensive. The achievement of both points is facilitated when geographical maps are available which contain frequency distributions and durations of suitable parameters of solar radiation, temperature and humidity of the air and precipitation for a given area. Since heat and cold are involved, such maps should be plotted both for summer and winter. Within each map, regions of equal conditions are demarcated. Maps of this kind are especially indicated in areas which have a great regional and seasonal meteorological variation. The information so accumulated, together with data on the production by animals of heat, moisture and metabolic waste products, helps the architect and engineer in the planning of buildings and ventilation systems. Work along these lines is in progress in Germany and Switzerland (Primault, 1972).

SUMMARY

The present animals, in contrast to wild animals, are selected and bred for productive traits. If subjected to severe meteorological conditions, particularly when transferred to tropical areas, domestic animals suffer from meteorological stress. The resulting strain varies according to species, breed, age and nutrition. Combatting meteorological stress requires extra energy, which means that less energy is available in the animal for productive processes.

Problems of cold arise in the first place in the young animal, which is at the disadvantage of having a large surface/mass ratio, a relatively poor thermal insulation and little energy reserves. Adult animals of large species, especially when acclimatized to cold, can tolerate temperatures well below freezing point.

High producing animals, owing to their high metabolic rate, generate much heat, which is difficult to dissipate in a hot environment. If body temperature rises, the appetite for (fibrous) feed diminishes. The resulting decrease in caloric intake reduces the animal's heat burden, but leads to a fall in production. Hot weather poses special problems for the transport of animals in containers.

Solar radiation can act upon animals by putting a heat load on them (infrared and visible rays), by producing sun burn and promoting the formation of vitamin C in the skin (ultra violett rays), and by stimulating sexual functions (visible rays).

High altitude problems, in particular pulmonary hypertension and its sequelae, are basically caused by hypoxia, but modified by cold, poor nutrition and physical exercise.

The indoor environment becomes increasingly important with animal production taking place in a factory like fashion ("bio-industry"). Deviations from optimal conditions of meteorological variables in animal houses can cause high economical losses.

Knowledge derived from the study of the interrelationships between the animal and its meteorological environment can be applied in two ways: either by adapting the animal to the (stressful) environment by selection and breeding, or by adapting the environment to the animal by technical and managerial means.

Suggestions for future consideration include the adaptation of selected meteorological indices (designed for man) for use in domestic animals, the construction of climogrammes, further extension of weatherforecast in relation to animal transport, and the elaboration of regional maps supplying information on temperature, humidity, radiation and precipitation for builders of animal houses and ventilation engineers.

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