

A MODEL OF RUMINANT HEAT TRANSFER

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SUMMARY

The problem of feed utilization and heat transfer as it applies to a ruminant is presented. A simple mathematical model of the situation is developed and used to predict the amount of heat that can be disposed of by an animal in terms of its size, ambient temperature, wind speed and water available to it for evaporative heat loss (perspiration). In terms of known digestion efficiency, it is shown that animals receiving excessive heat energy (e.g. exposed to sunlight and/or raised in temperatures above their blood heat) may have to reject their food because they are unable to dispose of the associated heat. Some of the implications of this with regard to protein/energy balance in tropical feed strategies are discussed. The particular advantages of enhanced microbe efficiency in the rumen and the use of by-pass protein for ruminant productivity in the tropics are suggested.

INTRODUCTION

Because of their ability to produce heat and also to control its dissipation, mammals can live in a wide variety of climatic zones. The underlying evolutionary advantage for maintaining homeothermic conditions is that the most important enzymatic reactions which sustain life are very temperature sensitiveⁱ. The central nervous system and the brain are therefore particularly vulnerable to fever-induced disorders of body chemistry. For this reason, mammals may go to extraordinary lengths to protect themselves from hyperthermiaⁱⁱ.

Ruminants, while having the same problems of temperature control as other mammals, also need healthy and procreative micro-organisms in the rumen if they are to convert cellulosic materials into useful biomass and proteins. The commensal relationship of mammals with micro-organisms is not unique to ruminants but the ubiquity (and utility to man) of ruminants is heavily dependent upon their ability to maintain a healthy rumen.

The fermentation of feed in the rumen and its subsequent digestion require energy. However, the process is not completely efficient and heat is produced as a by-product. This is called the "heat increment" of the food and, while it can be usefully disposed of in a cold climate, it can be a nuisance and a danger to health in a sustained hot and humid environment. Sir Kenneth Blaxter has written several books and papers on the subject of energy metabolism in animals, notably ruminants and manⁱⁱⁱ. A mathematical model of the heat transferred to and from a ruminant using his correlations is described in this paper and shown to predict the onset of both hypo and hyperthermia. By considering the relative contributions to the overall heat load experienced, various strategies to reduce the heat losses or gains of mammals can be suggested. One of the major strategies proposed involves the consideration of the diet and, in the particular case of ruminants, the diet of the rumen microorganisms.

THE BASIS FOR MATHEMATICAL MODEL

There are many factors which cause heat transfer but ultimately they all require that a temperature gradient

ⁱ. Blaxter, K. L. (1989) *Energy metabolism in animals and man*: Cambridge University Press, p129

ⁱⁱ. Taylor, C. R. (1970) *Dehydration and heat: Effects on temperature regulation of East African ungulates*. Amer. J. Physiol. 219:1136

ⁱⁱⁱ. Blaxter K. L. (1962) *The energy metabolism of ruminants*: Hutchinson, London.

exists. Similarly for evaporation to take place, there must be a concentration gradient of water molecules across the boundary layer surrounding a surface. This is measured as a humidity in kilograms of water per kilogram of dry air. Not surprisingly it is a function of temperature because the partial pressure of water increases with temperature (equaling one atmosphere pressure at its boiling point). It is convenient to consider the drying potential of air as a proportion of its saturation humidity. This is termed the relative humidity. Thus air with 100% relative humidity is totally saturated at that temperature and no more water can evaporate. If such air is cooled, water will condense from it as a dew or a mist. But in condensing, that water must give up its latent heat to enable the molecules aggregate and form liquid water. The converse is where water evaporates and extracts heat from its environment thus causing evaporative cooling. It should be noted that a relative humidity of 100% implies that no such cooling can take place.

Evaporative cooling is widely used by ruminants to maintain some measure of temperature control. However, different species may use different techniques or a combination of several (including perspiration, wallowing and panting). Most domestic cattle use perspiration from sweat glands and only pant in life-threatening situations^{iv} whereas water buffalo, having few sweat glands, must rely on wallowing. In addition, different varieties of an individual species are known to have a different density of sweat glands. Not surprisingly the ability to sweat among such varieties correlates quite well with the temperature and humidity experienced in their country of origin⁴. It follows that an animal moved from a temperate region to the tropics may be able to utilize previously underused sweat glands but it cannot be expected to grow more. As a consequence, relocated temperate-country animals will usually need greater protection from the heat than their indigenous cousins even after they have “acclimatized.”

In considering the comfort of houses, engineers and architects have to give consideration to insolation. This is the rate at which the sun’s energy strikes a unit area of roof. If solar heating is being considered, it is insolation that primarily determines its viability. But not all of the insolation falling on large ruminants such as cattle contributes to the heat load on the animals. If the coat is short, white and shiny it will reflect away much of the radiant energy (perhaps 30%)^v. If the coat is woolly and black, it may reflect only 10% of the incoming energy. Other factors which attenuate the incoming radiant energy are the humidity of air through which it travels (water vapor selectively absorbs several wavelengths of infra red energy) and dust. Thus the latitude and time of day both affect the length of absorbent air that the radiant energy must travel through. The actual area of the animal exposed to the direct and indirect radiation will also change with the time of day and season and as the animal moves. When incoming thermal radiation becomes excessive, cattle seek the shade or if none is available, seek to reduce their exposed profile: They also look for water which, ideally, is available to them in a shaded area.

The heating value of the available food has already been touched upon. Complete oxidation of the feed to carbon dioxide and water vapor would produce its heat of combustion (or calorific value). But only a proportion of the feed is so metabolized by the animal. And only a proportion of that metabolizable energy appears as thermal energy (the “heat increment”).

A major source of dietary protein for ruminants on a subsistence diet is known to be the excess bacteria produced in the rumen. (The animal probably has a limited control of such essential dietary inputs achieved by recycling some of the breakdown products of its own metabolism (typically urea) through its saliva back to the rumen). The half-life of bacteria and of amino acids within the animal itself are quite variable but death of the former and breakdown of the latter are inevitable. It follows that apart from the small amount possibly recycled through the saliva, there is a net loss of nitrogen from the animal in the urine and the feces. This must be replaced in the diet or the animal will suffer malnutrition and experience poor disease resistance. A valuable feature of the bacteria in the rumen is that they can use simple nitrogenous materials (which are inert or even toxic to its host) to produce essential components for the animals diet. For the heat stressed animal, it must be a delicate balance between the unwanted heat input from its food and the essential nitrogen compounds contained in the feed that it needs to sustain life. Nitrogen input and trace minerals in the diet are the essential components in the diet of the rumen bacteria which enable them to provide biomass having a minimal heat

^{iv}. Finch, V. A.(1986) *Body temperature in beef cattle: Its control and relevance to production in the tropics*, J. Anim. Sci 62:531-542

^v. Blaxter, K. L. (1989) *Energy metabolism in animals and man*: Cambridge University Press, p92 Table 7.4)

increment to their host. Ruminants being effectively a composite animal, are only healthy in a subsistence environment if the life-supporting bacteria in the rumen are operating efficiently^{vi}.

In summary it can be seen that heat inputs and outputs from a ruminant depend upon many levels of many factors. Any mathematical model must realistically reflect this multi-parameter problem.

^{vi}. Preston, T. R. and Leng, R. A. (1987) *Matching ruminant production systems with available resources in the tropics and subtropics* : Pernambul Books, Armidale, NSW Australia

Major parameters:

- 1 **Insolation** - anywhere between zero and perhaps 2000 W/m² of radiant energy could hit a ruminant. But the highest levels are usually limited to tropical desert areas or are of short duration: It is rare for cattle to be exposed to levels above about 500 W/m² of which as much as 90% may be absorbed. The type of coat and its color have a significant effect on the overall amount of radiation absorbed^{vii,viii,ix}. The animal has some limited control over the area exposed to insolation but, in general, larger animals receive more radiant energy. This may partly explain why small breeds are generally favored in the tropical grazing areas. Values of insolation are input into the model or calculated internally to complete the energy balance.
- 2 **Convective heat transfer** - heat lost to or gained from the air. This can be due to natural or forced convection. In the latter case wind-velocity is a factor. In both cases air temperature and skin temperature determine the rate of heat transfer. Air temperatures at which cattle are kept may typically range from -10°C to +40°C: Wind velocities from 0 to 10 m/s are not uncommon. By controlling blood circulation and effective thermal conductivity, the animal has some considerable control over its skin temperature. However, in the absence of evaporative cooling, the surface temperature may easily exceed blood temperature. Heat transfer coefficients for both natural and forced heat transfer are calculated in the model and averaged to provide a function of heat loss/heat gain which depends upon wind velocity.
- 3 **Evaporative heat loss** - heat lost as latent heat when the relative humidity around is less than 100%. The actual amount of perspiration will depend upon sweat gland density, air velocity, relative humidity and area exposed, as well as the availability of drinking water. Perspiration will only be visible as liquid when the relative humidity of the air is high or if the animal is distressed in some way (or both). The animal probably has some control over the amount of water evaporated and from where it loses it. (Losses are known to be in excess of 1kW/m² in heat stressed humans¹). The model allows for values of insolation to be input or calculated internally to complete the energy balance.
- 4 **The heat increment** caused by the diet and its inefficient processing. Unless it has a choice of feeds, the animal can only vary the amount of feed it eats. (See Blaxter¹ p205). If the animal eats up to 50 kg/day of a roughage having a heat of combustion of 10MJ/kg but only 40% of this heat is metabolized, and the composite heat increment lies between 41 and 75% (Blaxter¹ p277), the heat increment from diet could be anywhere between 0 and 500W. The model needs the proportion of feed to be metabolized and the heat of combustion to be input. The correlation presented by Blaxter and Boyne (1978)^x relating the proportion of energy utilized in terms of the P/E ratio is used in the model:

$$k_m = 0.947 - 0.0001(P/q) - 0.128/q$$

Where k_m is proportion of the feed used for maintenance, P is the protein content in g/kg and q is the proportion of the total available energy which is metabolizable.

5 **Metabolic heat.**

Comes from several sources:

vii. Hutchinson, P. C. D. and Brown, G. D. (1969) *Penetrance of cattle coats by radiation*: J. Appl. Physiol. 26:454

viii. Turner, H.G. and Schleger, A. V. (1960) *The significance of coat type in cattle*: Australian J. Agr. Res. 11:645

ix. Peters, K. J., Horst, P. and Kleinheisterkamp, H. H. (1982) *The importance of coat colour and type as indicators of productive adaptability of beef cattle in a subtropical environment*. Trop. Anim. Prod. 7:296.

x. Blaxter, K. L. and Boyne, A. W. (1978) *The estimation of the nutritive value of feeds as energy sources for ruminants and the derivation of feeding systems*. J. Agricultural Sci., Cambridge, **90**, 47-68

- * The microbial digestion of feed in the rumen (Increased rumen efficiency should generate less heat.);
- * The maintenance of the dynamic state of the tissue and the use of muscle tissue during work;
- Essential bodily functions (e.g. maintenance of cell homeostasis, conversion of absorbed products into tissue synthesis or reserve energy sources (largely fat and glycogen)).
- Oxidation of compounds in futile metabolic cycles because an unbalanced nutrient availability constrains their use for protein synthesis .

This resultant metabolic heat must be circulated around the body by the blood stream and excess conducted to the surface (or dumped through urine and feces). The animal has some considerable control over this conductance and can allow significant local variations in its body temperature (Blaxter¹ p197).

The maximum value of 15000 kJ/kg was chosen for the heat of combustion of the feed (comparable with a poor quality starch) but only the non-metabolized energy content was considered to appear as metabolic heat as described above. This is probably an underestimate because some of the energy which is metabolized to provide biomass will also eventually appear as heat that must be dissipated. Thus the appetite predicted by the model maybe double the true maximum appetite possible.

Minor parameters

- * **Panting and salivation.** These are really specialized evaporative losses and only occur in a stressed cattle. Heat losses by such mechanisms were not incorporated in the model.
- * **Stored heat.** It is known that many large ruminants can use the specific heat of their body to offset the heat of the day. Thus they can allow some of their mass to become cooled well below blood heat during the night to reduce the heat load during the day. This effect was ignored in the model.

- * **Miscellaneous heat flows.** Urine, saliva and feces can carry away small amounts of heat throughout the day. Drinking water and food can provide small amounts of sensible heat (or remove it) by virtue of their temperature. These losses were incorporated in the model as being the heat carried away in approximately twice the mass of non-metabolized food plus an arbitrary value of 5 liters/day for basic urine production.

The heat reflected and conducted from surfaces such as buildings was ignored. It is also known that about 15% of the heat associated with metabolism is lost directly via respiration⁴ but this has been considered as part of the evaporative heat loss in the model presented in this paper.

- * **Wallowing in water of mud.** These heat losses can be substantial (perhaps 700 W/m² Blaxter p119?). However wallowing is not common behavior for cattle, sheep or goats so it was neglected in the model.
- * **Mechanical work carried out by the animal.** The effect of mechanical work being carried out by the animal is to increase the metabolic rate and thus the heat load which must be dissipated into the environment. If the food intake and evaporative losses predicted by the model are considered as the minimum necessary for resting, the effect of additional mechanical work can be qualitatively assessed. If found to be necessary, future models could incorporate such a term.

The value of a heat balance analysis is that given a sufficient time base, the net energy flow should be zero. Periods of a year may be useful in determining feed economics but the increasing mass and surface area caused by growth would require that these factors are built into the model. Pregnancy, birth and lactation would also need special consideration. Because it represents a diurnal cycle, twenty four hours are customarily used as the time base for feed rates even though the mean residence time of food is about 60 hours in cattle and 47 hours in sheep (Blaxter¹ p26). Diurnal body temperature oscillation is part of the animal's strategy to combat feed shortage in periods of drought⁴.

In the model reported on in this paper, all energy flows are given in units of Watts (Joules/second). Conceptually this should be interpreted as the heat flow that would apply if the animal had to sustain the modeled conditions for many hours or if its heat management strategies were very limited. Problems of what constitutes a "standard metabolism" (Blaxter¹ p121) have been avoided in the model by considering a range of feed inputs and water evaporation.

The evaporative heat losses are given in kg/hour and represent a **minimal** water requirement for heat management by evaporation: The water needs for metabolism, urine, feces etc. are not included. The feed rate was calculated in kg/day.



RESULTS

The model treats a mammal as two horizontal cylinders and four vertical ones. This enables the steady-state Laplace equation

$$\frac{\delta^2 q}{\delta x^2} + \frac{\delta^2 q}{\delta y^2} = 0$$

to be easily solved for the radial flow of heat as:

$$q = k \cdot \frac{A_{\text{outer}} - A_{\text{inner}}}{t \ln(A_{\text{outer}}/A_{\text{inner}})} \cdot \Delta T$$

where q is the heat transferred, k is the thermal conductivity of the animal across a thickness t and A_{outer} and A_{inner} are the respective outer area of a cylinder and the inner “warm core” of the cylinder. ΔT is the difference in temperature between the two areas. When t is small, there is little error involved in using the external area of the cylinder in place of the log mean area presented above.

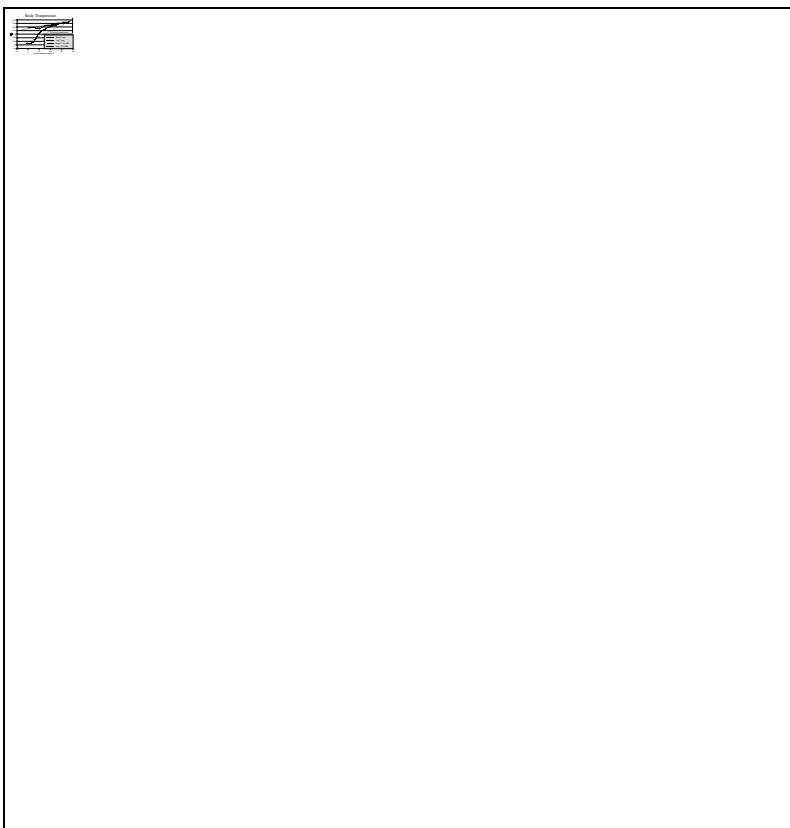


Figure 2 - Surface temperature of the animal as a function of air temperature

Figure 1

A similar equation to that presented by Blaxter¹ (Table 7.10) was used to indicate the heat that can be lost by convection. However the present model has been refined somewhat to take account of the known difference between heat convected from horizontal cylinders and vertical cylinders.

Although this model can be applied to any standing four legged animal under any conditions, it is necessary to constrain some variables to show relationships between the rest. Essentially a five dimensional model is being presented (Insolation, feed-rate, air temperature, air velocity and losses due to perspiration) in which the surface temperature of the animal is an intermediate calculation.

Figure 2 shows the expected surface temperature of the animal as a function of ambient temperature if the insolation and evaporative losses are zero and the wind velocity is less than

1 m/s. This is the surface temperature which equates heat conduction through the animal from a source at 39°C to the heat lost by convective heat transfer to the noted ambient temperature. Two body thicknesses were chosen as 15 mm and 150 mm which roughly indicate the expected temperatures of the back and the thigh of the beast. The predictions are in agreement with the results presented by Gonzalez-Jimenez & Blaxter^{xi} (1962) for an unknown evaporative heat loss, feed intake, insolation, wind velocity and area. (The model used to develop the results shown in Figure 2 uses a cylinder 656 mm in diameter and 1200 mm long for the body, 250 mm diameter and 300 mm long for the neck and head, and four vertical cylinders each of 100 mm in diameter and 600 mm in length for the legs and is of the form shown in Figure 1.)

Figure 3 shows the proportion of the total heat lost to the environment by convection from the body, the legs and the head/neck if they all had the same surface temperature and if wind velocities were less than 1 m/s. It can be seen that the legs account for 30 to 35% of the heat losses and that this proportion shows little variation with ambient temperature.

Similar results are obtained at higher wind velocities although the known velocity profile close to the ground shows that the proportion of the total heat specifically lost by the legs decreases. Simple aerodynamics indicates that heat conservation during a cold wind and little sunlight would be favored by the animal crouching with its hind end facing the wind. In contrast, in hot arid areas, heat conservation would be best attained by standing with the hind end facing the sun and/or with the body broadside to the wind. (Of course this behavioral strategy would be modified if sand or dust were being carried by the wind.) In a hot humid climate where shelter from the sun is available but optional, the healthy animal can be expected to leave such shelter only by night. This will enable it to enjoy cooling breezes without encountering high insolation. (This behavior has been reported by Beede and Collier^{xii}). An excellent review of the major strategies available has been prepared by Blackshaw and Blackshaw (1994)^{xiii}

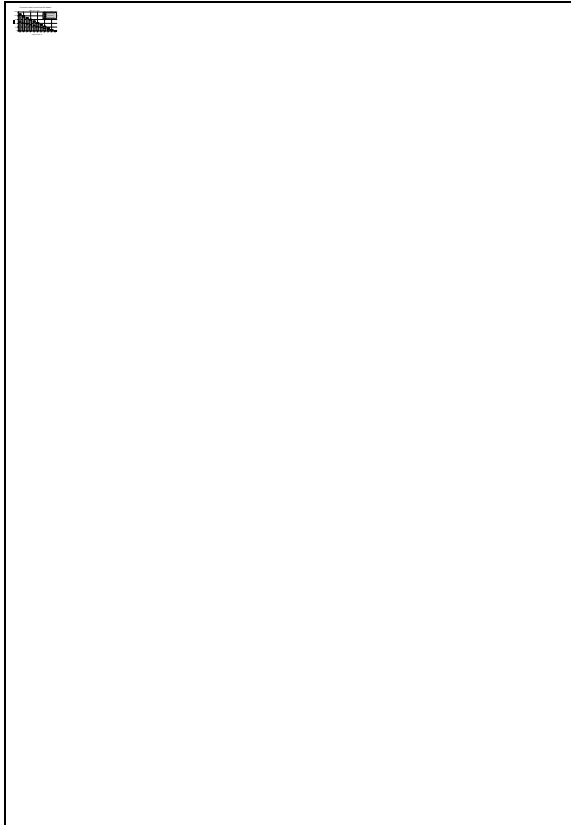


Figure 3 - Convective heat losses

^{xi}. Gonzalez-Jimenez, E. and Blaxter, K.L. (1962). *The metabolism and thermal regulation of calves in the first month of life*. Brit. J. of Nutrition, **16**, 199-212

^{xii}. Beede, D. K. and Collier, R. J. (1986) *Potential nutritional strategies for intensively managed cattle during thermal stress* J. Anim. Sci. 62:543-554

^{xiii}. Blackshaw, J. K. and Blackshaw, A. W. (1994) *Heat stress in cattle and the effect of shade on production and behaviour: a review*: Austral. J. of Experimental Agri. **34**, 285-95

Figure 4 shows that for any desired feed rate, there is usually a minimum need for water to be evaporated to dispose of the heat increment. The figure presented is for cattle experiencing no insolation and with a negligible wind velocity. The back plane of the figure represents the situation where the relative humidity is 100% and no significant evaporative heat loss is taking place. Under these conditions, all heat losses are convective or occur by passage of urine and dung. (It is assumed that the animal had unlimited access to potable water so that urine flow is not limited).

Figure 5 shows the effect of insolation on the heat balance experienced by

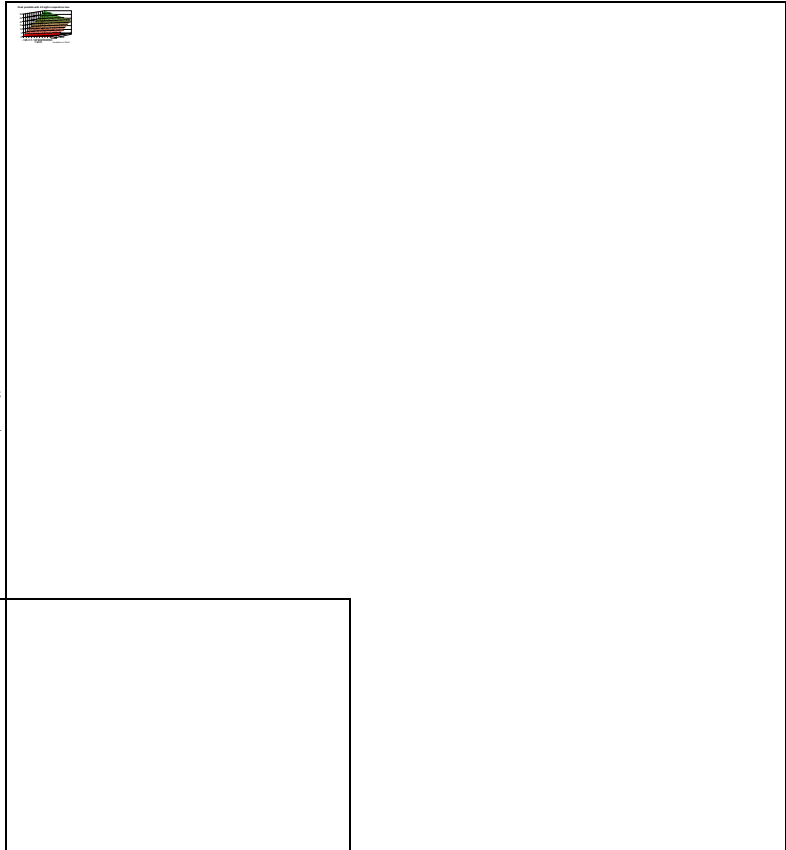


Figure 4 - Maximum feed intake possible

cattle. If relative humidity restricts the water evaporation rate to 0.5 kg/hour, it is apparent that the feed intake will be limited by the air temperature and by the insolation received.

At low ambient temperatures and insolation, the animal must eat substantial amounts of food to obtain energy: Any heat increment is an advantage. Its primary requirement is for an oxidizable substrate (such as fat and short-chain volatile fatty acids)

Figure 3 - Maximum feed a function of perspiration loss and ambient temperature.

which is sufficient in absolute terms and also relative to the lesser requirements for amino acids to achieve tissue synthesis. Figure 5 shows that with a feed which is 60% metabolizable and in which 20% of the available energy goes to form body heat, about 30 kg of dry feed will be required per day to satisfy the energy balance. Even if this is available, there is a limit to how much the body can process in a given time. As a consequence, either the animal uses its own reserves of metabolizable tissue or it runs the risk of losing the heat balance with resultant hypothermia. A practical solution is to keep animals inside a building sheltered from cold winds and to provide the animals with a feed having a relatively low P/E ratio. Any resultant heat increment under these circumstances is likely to be advantageous. These are both standard practice during the winter at high latitudes. But a side-effect is that it makes the animal totally dependent upon the human farmer to select the right balance of protein to energy (P/E) in whatever feed is available.

As the received radiant energy (insolation) increases, less feed is required (or its metabolizable heat content may be reduced). i.e. the P/E ratio required by the animal can be increased.

In contrast, at high ambient temperatures, and high incoming thermal radiation, but low humidity, the animal has difficulty in eating anything which involves a significant heat increment. Its appetite can be expected to increase only if it is sheltered from the sun. Provided sufficient water is present, the appetite of the animal will also increase if it exposed to the wind because increasing wind velocity increases both the rate of evaporative

cooling and the rate of heat transfer by convection. (The exception is when the air has a temperature higher than the deep body temperature and when its humidity is also approaching saturation). Where the humidity is low, increased water consumption is associated with thermal stress^{xiv,xv}. Even between 20 and 30°C, cows have shown an increase of perspiration loss of 176% in chamber studies^{xvi}. Several authors have noted the associated loss of minerals¹². Throughout much of Africa and tropical Asia, milk cows are kept under some sort of roof to shield them from the sun. This has the result that, just as in the sub-arctic winter, the animals are totally dependent upon humans for the selection of their feed. It follows that such a feed should ideally have a low heat increment while providing adequate nitrogen for protein synthesis and sufficient minerals (notably K, Na, Mg and Cl) to replace those lost in perspiration.

At high ambient temperatures and as the relative humidity rises, heat losses from evaporation become much less. Figure 6 presents the situation when the surrounding air is saturated with moisture. Obviously appetite must be depressed or the heat increment of the feed reduced if the animal is to maintain homeostasis. The animal now needs a substrate where the oxidizable content for heat production may be effectively zero. The resulting P/E ratio in the nutrients required by the animal is therefore increased even where total nutrient requirements are decreased. If this extra protein is not supplied, the animal starts to suffer heat stress (hyperthermia). In ruminants this condition is typically indicated by excessive respiration rates, reduced feed intake and some hormonal changes¹². This reduced appetite has the desirable effect of reducing the heat increment associated with fermentative digestion but it also reduces the heat released in fertile cycles of metabolism such as the synthesis of milk or tissue. So although the heat input is once more in balance with the heat losses, such an animal will degenerate and die because it is losing protein faster than it can be replaced. Even where there is no insolation (e.g. in sheltered pens), the appetite and response of animals cannot be expected to be the same in both tropical and temperate feed trials as is shown by the general left-to-right slope of the plane in Figures 5 and 6 which reflect changing ambient air temperatures.

We must conclude that feed trials which do not report ambient humidity, air temperature and insolation are unlikely to be comparable. And a feed composition found to be satisfactory in one tropical location may cause a depressed production rate in another, otherwise similar tropical location. Satisfactory rations devised in temperate countries will have only limited relevance to the tropics unless, fortuitously, the otherwise comparable animals can access more water, are more sheltered from the sun (but less from the wind), and the humidity experienced is generally lower. Some of these fortuitous combinations are indicated by the (approximately) horizontal shaded bars in Figures 5 and 6.

STRATEGIES TO ENCOURAGE APPETITE IN TROPICAL CATTLE

- ^{xiv}. Johnson, H. D. and Yeck, R. G. (1964) *Environmental physiology with special reference to domestic animals LXVIII. Age and temperature effects on TDN, water consumption and balance of dairy calves and heifers exposed to environmental temperatures of 35 to 95°F*: Missouri Agr. Exp. Sta. Res. Bull. 865
- ^{xv}. McDowell, R. E. (1972) *Improvement of Livestock Production in Warm Climates*: W. H. Freeman and Co., San Francisco, USA
- ^{xvi}. McDowell, R. E. and Weldy, J. R. (1967) *Water exchange of cattle under heat stress*. Biometeorol. 2:414

Figure 5 - Maximum feed possible when air is saturated with

From the results presented above it can be seen that ruminant appetite should be improved by:

- sheltering the animals from the sun's radiant energy¹³;
- keeping them cool and well ventilated;
- providing an adequate cool water supply;
- using a variety bred and conditioned to the tropics⁴ (i.e. having many sweat glands and perhaps an enhanced ability to recycle some of its own nitrogen (perhaps *Bos indicus* rather than *Bos taurus*);
- providing the animal with a diet high in available nitrogen and minerals and low in incremental heat.

The opportunities offered by this last option deserve closer attention.

PROTEIN SOURCES FOR RUMINANTS

Ruminants in meadow land or savanna have a wide range of plants available to them. Low shrubs and trees may provide useful forage high in nitrogen to offset the high cellulose content of dry grasses. But a more usual nitrogenous diet for cattle are smaller leguminous plants. Thus a free-ranging animal normally has some control over the P/E ratio of its feed. Unless the protein in the diet is protected, the bacteria in the rumen will utilize it to make biomass. The special commensal relationship between the ruminant and its rumen population means that the animal gets much of its protein from bacterial biomass. This source becomes particularly important in times of drought or in winter. The use of protein concentrates, cottonseed cake and alfalfa hay to sustain cattle during such periods are well-used farming strategies limited only by the availability of concentrates, cottonseed cake and alfalfa. Alternatives such as *Leucaena sp* and molasses-urea blocks may have considerable value in the tropic ruminant husbandry.

Molasses is an important source of multi-minerals, particularly for ruminants. The presence of non-crystallizable sugars in the molasses provides a ready source of energy with a small heat increment. If urea or another nitrogenous source is incorporated into the molasses, the improved health of the rumen bacteria facilitates the digestion of poor quality roughages while keeping the apparent P/E ratio high. (The word "apparent" is used here because the additional protein comes from the biomass in the rumen and not from the feed directly.)

Urea molasses multi-nutrient blocks (UMMB) have been designed to provide urea, a complete mixture of minerals (including sodium chloride) and some slowly degradable protein (see Sansoucy, Aarts & Leng 1987^{xvii}). In many cases their regular use has doubled milk yield, produced a positive weight gain during drought, improved fertility and calf-rearing ability, enhanced appetite, improved efficiency of roughage conversion and also assisted in improving disease resistance and recovery. All of these advantages have been attributed to improved health and activity of the rumen biota. It is suggested that some of these beneficial effects may come about because the heat energy liberated in the digestion process (heat increment) is reduced by higher proportion of metabolizable nitrogen to energy in the feed and the resultant healthy rumen biota. The value of the urea molasses multi-nutrient block has recently been used as a vehicle for successfully introducing a base dose of anthelmintics into Indian^{xviii} and Fijian ruminants.

SOME IMPLICATIONS AND CONCLUSIONS

A relatively simple steady-state model based on the data published by Blaxter¹ and incorporating some additional aspects of heat transfer theory has been constructed. It has yielded some useful insights into the constraints experienced in animal husbandry. In particular, the dramatic effects of insolation and evaporative heat losses on animal appetite are indicated.

Much published research literature seems concerned with observed differences between research results

^{xvii} . Sansoucy, R., Aarts, G. and Leng, R.A. (1987) *Molasses-urea blocks as a multinutrient supplement for ruminants* [pp. 263-278 in *Sugarcane as Feed (Vol 2)* eds: Sansoucy, R., Aarts, G. and Preston, T.R.] Proc. Of an FAO Expert Consultation held in Santo Domingo, July 1986

^{xviii} . Sanyal, P.K. and Singh, D.K. (1993) *Prophylactic and therapeutic efficacy of prolonged low level administration of fenbendazole through urea-molasses blocks against experimental haemonchosis in calves*. J. of Veter. Parasitology, **7**, 71-80

obtained from feed trials at different sites. The provision of climatic details such as relative humidity variations, wind velocities, levels of insolation or even air temperatures that pertained during the feed trial is rare. The results presented in this present paper show that these parameters are significant and are required to make fair comparisons between reported feed intakes. If the noted differences in research results are really a reflection of climatic differences, then the nutritional value of a poor quality forage would apparently vary with the climate, availability of water and the dietary supplements used. We could also reasonably expect that the response to balancing the nutrients available to the actual requirements would have a greater effect on tropical production rates than temperate ones. Even more disturbingly, it may throw into question the validity of much otherwise valuable work carried out in temperate countries when the results are subsequently applied to the tropics.

If the major restraint on appetite is the extra metabolic heat resulting from nutrient imbalance, then large responses in feed intake can be expected when such materials as bypass proteins are introduced into the diet. Similarly correcting rumen deficiencies will both increase digestibility; and increase the effective P/E ratio in nutrients from microbial digestion taking place in the rumen. This will result in a decreased heat load from both heat of fermentation and from metabolic heat. The outcome will be reduced heat stress, improved yield and an increased appetite.

These conclusions may go some way towards explaining the remarkable (but variable) effects of urea molasses multi-nutritional blocks on animal production and milk yield throughout the tropics.

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