
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Proceedings of the N.Z. Society of Animal Production, 41: 152-162 (1981)

THE HEAT OF WARMING FEED

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SUMMARY

The results of a number of experiments in which sheep and cattle consumed high moisture feeds (10% dry matter) at a range of feed temperatures (1 to 38 °C) and over a range of air temperatures (+10 to −20 °C) were summarised. Responses to cooling were a reduction in heat loss and a decline in body temperature which could be accompanied by an increase in heat production. The efficiency with which surplus metabolic heat was used to warm feed was 50-60%. The pattern of heat flow from the body to the rumen, which was a function of the quantity and temperature of the feed consumed, determined the animal response. The heat flow from the body to the rumen was included as an additional heat loss in the conventional heat loss model.

The consumption of large meals of cold (2 °C) high moisture feeds by sheep and cattle can raise their critical temperature by 15-20 °C. This change may not affect the heat production of well-insulated, well-fed sheep or cattle. However, less well-insulated sheep and cattle at maintenance levels of feeding are likely to increase their heat production, at the expense of body tissue deposition to meet the thermal demands of the heat of warming.

INTRODUCTION

Animals generally consume feed with a temperature below body temperature. The heat required to raise cold (1 to 5 °C), high moisture (80-90%) feeds to body temperature (heat of warming) can be 15-20% of the daily total heat production of the animal (Table 1).

TABLE 1: EXAMPLE OF THE CALCULATION OF THE HEAT OF WARMING.

Given:	A 50 kg sheep, grazing for 8 h per day, eating 2.5 g DM per min. Pasture 12% DM and ambient temperature 10 °C. Daily heat production of sheep 6.5 MJ.		
Thus:	Daily DM Intake		= 1.2 kg DM
	Daily fresh matter intake		= 12.0 kg
	Temperature rise	38 °-10 °	= 28 °C
Hence:	Heat required to raise feed temperature (heat of warming)		= 10.8 x 28 x 4.18
			= 1.26 MJ
Hence:	Heat of warming as % daily heat production		$= \frac{1.26}{6.5} \times \frac{100}{1}$
			= 20%

Drew (1968), Barry *et al.* (1971) and Nicol and Barry (1981) have suggested that the energy cost to the animal of warming feed may contribute to reduced animal performance during winter in New Zealand. Calves drinking cool milk (Tayler and Londsdale, 1969) and pigs consuming cool whey (Holmes, 1971a) have gained liveweight more slowly than when the feed was warm. Shivering, which resulted in an elevation of metabolic rate, has been recorded in calves drinking cool milk (Holmes, 1971b). On the other hand liveweight gain in sheep for which snow was the only source of water was similar to that in sheep with access to drinking water (Butcher, 1973).

The work reported here summarises a series of experiments made on both sheep and cattle at the University of Alberta to determine the conditions under which the heat of warming contributes to the thermal balance of domestic livestock.

EXPERIMENTAL METHODS

Experiments on both sheep and cattle were mostly made over 4 h periods consisting of consecutively — 1 h pre-treatment, 1 h treatment and 2 h recovery periods. Longer experiments (3 weeks) were also made. Treatments consisted of several combinations of feed temperatures (−8 to +38 °C), environmental temperatures (+10 to −20 °C) and physiological states of the animal (level of insulation; level of feed intake; fed or not fed). Feed was either turnips (12% dry matter — DM) or a simulated low-moisture ration (10% DM) consisting of a pellet (50% barley, 50% lucerne) and water infused into the rumen.

During each experiment a number of body temperatures (rectal, ear, leg and trunk skin and rumen) were continuously recorded using copper-constantan thermo-couples. Respiratory gaseous exchange was measured using a ventilated hood and the open circuit indirect calorimetry system described by Young *et al.* (1975). Where oxygen, carbon dioxide and methane was measured, metabolic heat production was calculated using the equation of Brouwer (1965) and when only oxygen consumption was measured, the simplified equation of McLean (1972) was used. During all experiments the animals were held in metabolism crates.

All data were subjected to analysis of variance using appropriate linear models for each particular experiment. Multiple comparison of means was by a Student-Newman-Keuls test. Statistically significant interaction means were compared by the Cicchetti approximation.

RESULTS AND DISCUSSION

(a) Cooling in the Mouth or Rumen

The heat gained by a bolus in the mouth was calculated from intercepted boli at the cardia of feeding rumen fistulated steers when the DM and temperature of the ingested feed and the collected boli was known. These data showed that between 6 and 15% of the total heat required to warm the bolus to body temperature was contributed before it reached the rumen.

In another experiment no important differences in oxygen consumption or body temperatures were detected in steers fed cold (2 °C) turnips or warm turnips (27 °C) plus an equivalent level of rumen cooling using a cooling coil. Consequently, data from experiments in which rumen cooling simulated the consumption of cold feed were accepted as representative of the real situation.

(b) Change in Body Temperatures with Rumen Cooling

Fig. 1 shows typical changes of body and rumen temperatures in woolly (10 cm fleece depth) sheep consuming the equivalent of 2.5 kg fresh feed of 10% DM at 1 °C. The decline in skin temperature with rumen cooling was slow. Lack of stimulation of peripheral receptors may have limited the peripheral vasoconstriction response. On the other hand decline in deep body (rectal) temperature was substantial (1 °C). The overall temperature decline was sufficient to increase metabolic rate (maximum of 30%) over the latter stages of cooling and during the recovery period. Both the temperature and metabolic responses were similar, qualitatively, to those reported by Holmes (1971b) with young calves drinking cool milk.

(c) The Pattern of Heat Flow into the Rumen in Response to Rumen Cooling from Cold Feeds

The quantity and pattern of heat flow into the rumen in response to rumen cooling was calculated from the change in rumen temperature when rumen volume was known. Fig. 2 illustrates the heat flow into the rumen of a 45 kg wether with a rumen volume of 5.5 to 6 litres which received cooling equivalent to the consumption of 2.5 kg (fresh weight) of a 10% DM feed at 19 °C over a 1 h period, with (fed) or without (not fed) the actual feed DM.

When feeding accompanied rumen cooling the heat flow from the body to the rumen was reduced by 20 to 40% and the rate of

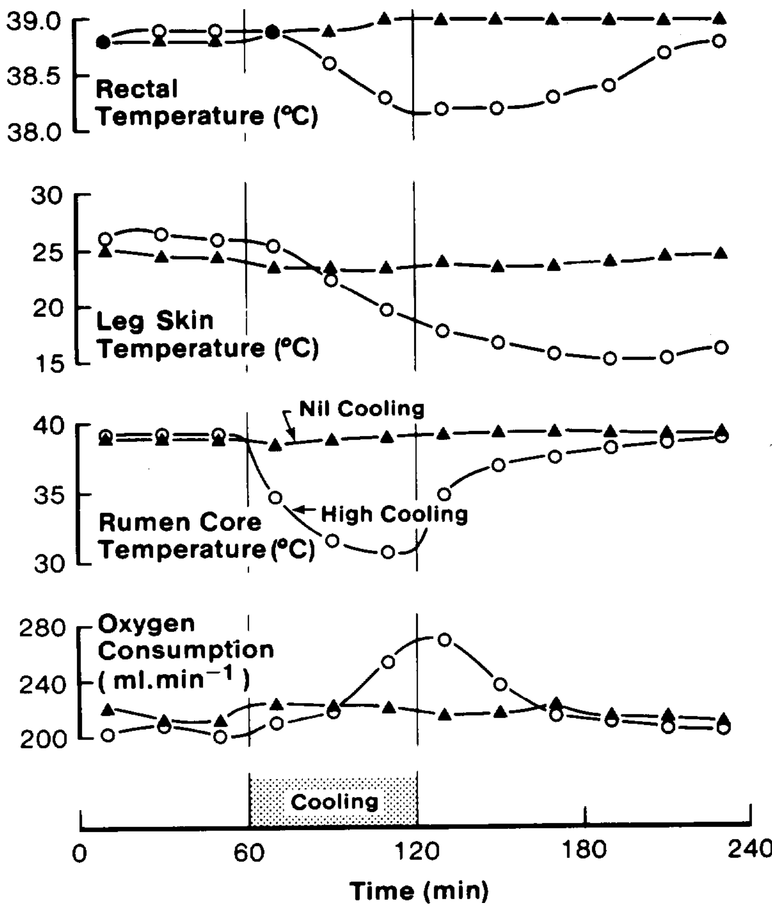

FIG. 1: *Time course of change in rectal, leg skin and rumen temperature and oxygen consumption of sheep receiving zero (solid symbols) or 420 kJ (open symbols) of rumen cooling.*

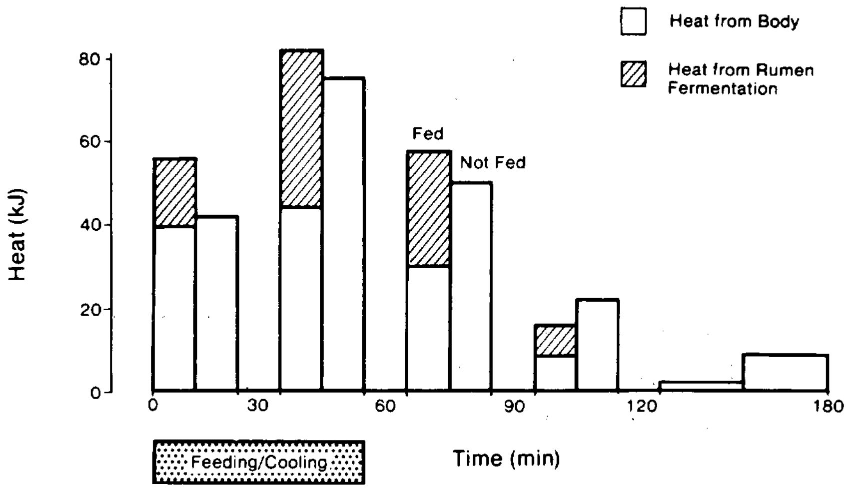

FIG. 2: *Heat flow into the rumen of sheep during and following 210 kJ of rumen cooling over 1 hour.*

recovery of rumen temperature post-cooling was more rapid. The contribution of fermentation heat production over 3 h was 30 to 40 kJ/MJ of digestible energy. Webster *et al.* (1975) estimated that the heat of fermentation over a 24 h period was 30 to 60 kJ/MJ digestible energy but did not give an hourly or diurnal pattern to fermentation heat production.

Heat flow from the body into the rumen was as great in the first 30 min after cooling as in the first 30 min of rumen cooling and 95% (not fed treatment) and 100% (fed treatment) of the net cooling of the rumen had been recovered by the rumen within two hours after cooling ceased. Only 55-65% of the total heat flow into the rumen occurred during the actual rumen cooling phase. The effect of the heat of warming was therefore not restricted to feeding periods, but neither was it a consistent heat flow over 24 h as implied by Blaxter (1962).

The profile of heat flow from the body into the rumen is dependent on the heat of warming (a function of the temperature, DM content and quantity of food consumed) and the amount of fermentation heat (a function of the quantity of feed consumed). By combining the results of experiments with both sheep and cattle a linear relationship predicting the heat flow from the body to the rumen over feeding from the heat of warming was demonstrated.

$$Y = 0.056\ (\pm 0.002)\ x - 1.39\ (R^2 = 0.98,\ RSE = 0.26\%) \quad \ldots (1)$$

where Y = heat flow (% digestible energy consumed per h) into the rumen from the body and X = the heat of warming per unit digestible energy intake per h (kJ.MJ DE/h).

Temperature of the feed had more influence on the heat flow into the rumen than did rate of eating the feed. A simplified prediction of the heat flow into the rumen from the body can be made by assuming that all high-moisture feeds have a DM content of 10% and a digestible energy concentration in the DM of 14.5 MJ DE/kg DM. Then, for every 1 °C fall in feed temperature below 33 °C, 2 kJ/h of heat would flow from the body to the rumen per kg of fresh feed eaten per h. With a feed temperature above 33 °C, the relationship predicts a heat gain by the animal from the rumen as a result of microbial fermentation in the rumen.

Further refinement of the prediction of heat flow into the rumen during eating would be possible with adequate knowledge of the actual rates of eating, total time spent eating and rumen temperature changes associated with eating under field conditions.

(d) Interaction of Environmental Temperature and Heat of Warming

The heat production of four steers was measured at +10, −8 or −20 °C for 2 h immediately after they had eaten turnips at either −8 °, 2 ° or 27 ° or turnips (2 °C) plus hay in a 10 °C environment. The mean heat production of these steers over the 2 h post-feeding period is shown in Table 2.

TABLE 2: HEAT PRODUCTION ($W.m^{-2}$) OF STEERS OVER 2 h EXPOSURE TO AMBIENT TEMPERATURES OF +10, −8 AND −20 °C IMMEDIATELY FOLLOWING CONSUMPTION OF TURNIPS FED AT A RANGE OF TEMPERATURES.

Feeding treatment	*Ambient temperature (°C)* +10	−8	−20	*Feeding treatment mean (SEM ± 11w/m²)*
Turnip 27 °C	99	120	146	122e
Turnip + Hay 2 °C	103	106	151	120e
Turnip 2 °C	112	122	178	137ef
Turnip −8 °C	127	149	195	157f
Ambient temperature (SEM ± 9 $w.m^{-2}$)	110a	124ab	168b	

Heat production was elevated in steers eating frozen turnips, in all steers at −20 °C and in steers measured at −8 °C after eating cold (2 °C) turnips. In these seven treatments therefore the steers were outside their zone of thermoneutrality and thus below their critical temperature (T_c). These non-thermoneutral heat production data were used to calculate the separate effects of environmental temperature and the heat of warming on heat production by linear multiple regression. The equation was:

$$Y = 96 - 2.45\ (\pm\ 0.57)\ X_1 + 0.165\ (\pm\ 0.055)\ X_2 \ldots (2)$$
$$R^2 = 0.83,\ RSE = 13\ W.m^{-2}$$

where Y = mean heat production ($W.m^{-2}$) over the period 2 h post-feeding, X_1 = ambient temperature (°C) and X_2 = the heat of warming per meal ($W.m^{-2}$).

Thus, for every °C decline in ambient temperature below critical temperature, heat production rose by 2.45 $W.m^{-2}$. This was well within the range for total body conductivity of steers as reviewed by Thompson (1973). The critical temperature (T_c) of these steers during the post-feeding period was calculated as described by Blaxter (1962). In the absence of any cooling from food, T_c was calculated to be −2 °C. T_c rose by 3.5 °C to +1.5 °C when turnips were fed at 27 °C; to +7 °C with cold (2 °C) turnips; and to +20 °C where frozen turnips had been consumed.

(e) Efficiency of Heat Substitution

When the heat available (in excess of minimum heat loss and produced in response to rumen cooling) was compared with the calculated heat flow into the rumen in experiments with both sheep and cattle (Table 3), the heat available was generally in excess of that required, suggesting that the substitution of metabolic body heat for the heat required to raise the temperature of the rumen contents may not be 100%. The data in Table 3 were used in a multiple regression equation constrained through zero, to compute the apparent efficiency with which surplus and additional heat was used.

The apparent efficiency of substitution of surplus and additional heat was 0.47 and 0.67, respectively. Both coefficients were significant ($P<0.05$) and the coefficient of determination (R^2) was 0.85. The data available from this study were limited and confirmation of this efficiency of heat substitution is required. However, in prediction of the potential increase in heat production due to the consumption of cold food or water, some correction for the possible inefficiencies of heat substitution may be appropriate.

TABLE 3: COMPARISON OF THE HEAT OF WARMING WITH THE EFFECTIVE RUMEN COOLING, SPARE AND ADDITIONAL HEAT PRODUCTION OF CATTLE AND SHEEP.

	Cattle experiment (15 kg turnips fed over 1 h) Feed temperature (°C treatment)				*Sheep experiment (10% DM fed at 2°C) Feed intake (g DM/kg $LW^{0.75}$/d)*				
	27°	*2° + hay*	*2°*	*−8°*	*20*	*35*	*55*	*80*	*110*
Effective rumen cooling ($W.m^{-2}$)									
by calculation [1,3]	−5	8	11	43	7.5	12	17	25	34
from regression	5	14	17	48					
Heat production ($W.m^{-2}$)									
at +10°C									
spare [2]	29	29	29	29	3	13	25	40	64
de novo	0	4	13	28	5	4	1	4	−3
total heat above H/min.	29	33	42	57	8	17	26	44	61
at −20°C									
spare	0	0	0	0	0	0	0	0	21
de novo	3	8	35	52	−2	17	40	32	27
total heat above H/min.	3	8	35	52	−2	17	40	32	48

[1] by calculation = calculated from rumen volume and temperatures (cattle experiment); from regression = predicted from the regression of HW on heat production (Equation 2).

[2] spare = Heat production in thermoneutrality in excess of minimum heat loss (H/min.); de novo = Heat produced in response to ruminal cooling.

[3] by calculation = from heat of warming per meal and Equation 1 (sheep experiment).

(f) The Heat of Warming Model and Critical Temperature

The heat of warming can be incorporated into the conventional heat loss model (Monteith and Mount, 1974) by treating heat flow into the rumen as an additional source of heat loss from the body which will elevate minimal heat loss. Consequently T_C will be raised while heat flows into the rumen from the body in response to the ingestion of cold feed.

The T_C of sheep and cattle under various insulative and climatic conditions has been calculated (Blaxter, 1962; Alexander, 1974; Webster, 1974). These T_C have been re-calculated to include the effects of the consumption of feed of 10% DM at 3 °C. Heat flow into the rumen during feeding was assumed to be 2 kJ per kg fresh feed consumed per h (see section c). Sheep were considered to consume 1.6 kg fresh material per h and cattle, 10 kg fresh material per h. Calculated rates of heat flow into the rumen are therefore 22 and 35 $W.m^{-2}$ for sheep and cattle, respectively. On these assumptions, T_C would be elevated by 15 to 18 °C for cattle and 15 to 20 °C for sheep during the hour of feeding (Table 4).

This elevation in T_C of well-fed woolly sheep or lactating dairy cows may still not result in departure from thermoneutrality but for cattle fed at maintenance or only slightly above and for sheep with lower insulation (< 40 mm fleece), the rise in T_C may cause a temporary departure from thermoneutrality during, and for some time after, the feeding period. Under certain circumstances in the present studies, daily heat production was elevated 10 to 20% as a result of the consumption of cold feed.

CONCLUSIONS

The heat energy required to warm ingested feed is a component of heat energy balance which may influence the productivity of livestock fed high-moisture forages. Lack of appreciation of the importance of the heat of warming results from inadequate knowledge of the heat flow from the body into the rumen under pasture grazing during winter.

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TABLE 4: EXAMPLES OF CALCULATED CRITICAL TEMPERATURES OF SHEEP AND CATTLE INCLUDING THE HEAT OF WARMING.

Animal	*Insulation*	*Level of production*	*Climate*	*Total/body thermal insulation (°C/m^{-2}/W)*	*Heat production (W/m^{-2})*	*Non-feeding*	*During feeding*
Weaner steer	winter hair cover	maintenance	dry +	0.50	120	−12	+5
	thin hair cover	maintenance	calm	0.40	120	−2	+12
	winter hair cover	0.5 kg/d	calm	0.50	155	−30	−12
Beef cow	winter coat	maintenance good condition	dry + calm	0.54	107	−13	+6
	winter coat		dry 16 k/h wind	0.42	107	−2	+12
	winter coat		raining 10 k/h wind	0.37	107	+4	+17
Dairy cow	summer coat	20 litre/d milk	dry	0.45	154	−23	−7
Ewe	Woolly 100 mm	maintenance	dry	1.1	60	−11	+13
	Shorn 7 mm	maintenance	dry	0.24	60	+28	+33
	Woolly	2/3 pregnant	dry	1.1	90	−42	−18
	Shorn	2/3 pregnant	dry	0.24	90	+20	+25

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