Energy Requirements of Dairy Cows under High Temperature Conditions

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Abstract

It is well recognized that heat stress causes the decrease in voluntary feed intake and milk production in dairy cows. Heat stress also affects energy requirements due to the higher metabolic activities and increase in the investment for heat dissipation to cope with the stress. This report deals with the effects of environmental temperatures on energy metabolism of dry and lactating cows with a view to determining the energy requirements for maintenance and production of milk plus body tissues in hot environments. The net energy requirements of dry cows for maintenance derived from fasting metabolism were almost constant at 18°, 27° and 32℃ and tended to increase by about 5% at 36℃. However the metabolizable energy (ME) requirements of dry cows given roughages for maintenance started to increase at lower environmental temperatures than 32℃. It is considered that heat increment acts as a promoter of heat stress from the inner part of the body at high environmental temperatures. The increase in the ME rquirements for maintenance was affected by the type of roughage administered due to the difference in heat increment among roughages. The energy requirements of lactating cows increased at high environmental temperatures. The increase seemed to be mainly caused by the increase in the ME requirements for maintenance.

Introduction

Heat stress in a hot climate reduces feed intake, milk yield and alters the milk composition. Since there is a significant correlation between the degree of increase in body temperature and the rate of decrease in milk production at high environmental temperatures (Okamoto *et al.*, 1965), to maintain a high production it is essential to minimize the increase in body temperature of dairy cattle (Shibata and Mukai, 1979). However, body temperature results from the balance between heat production and heat loss. Therefore, studies aimed at clarifying the relationship between the type of ration and heat increment, which is considered to be a promoter of heat stress from the inner part of the body at high environmental temperatures (Shibata and Mukai, 1977 ; 1979), must be carried out under high temperature conditions.

On the other hand, McDowell *et al.* (1969) suggested that the energy requirements per unit of body mass for lactating cows increased at high temperatures. Also, a reduction in the efficiency of conversion of feed energy units to production energy units during heat stress has been reported in lactating cows (Wayman *et al.*, 1962 ; McDowell *et al.*, 1969 ; Shibata and Mukai, 1979). The reduced efficiency was presumably due to the effect of the increase in body temperature on the metabolic rate (Hales and Findlay, 1968) and energy expended in ridding the body of excess heat load by the increase in respiration and other related activities. However, there are few quantitative studies on the effect of environmental temperatures and the type of ration on heat increment and energy requirements in dairy cows.

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This report deals with the effects of environmental temperatures on energy metabolism of dry and lactating cows with a view to identifying the energy requirements as well as with the relationship between the change in heat increment and that in energy requirements in a hot environment.

Materials and methods

Four experiments were carried out, using either dry or lactating non-pregnant Holstein cows housed in the energy metabolism laboratory of the Kyushu National Experiment Station, to determine the energy requirements for maintenance and production of milk plus body tissues at high environmental temperatures. Energy balances of cows were measured by means of open-circuit indirect calorimetry.

Experiment (Expt.) 1 : Fasting metabolism of 4 dry cows was measured to determine the net energy requirements for maintenance. Two of 4 cows were subjected to 3 temperature treatments in the order of 18°, 27°, 36℃ at a relative humidity of 60%, while the other two were subjected to the same temperature treatments in the reverse order.

Expt. 2 : Energy balances of 4 dry cows were measured to determine the energy requirements for maintenance. Cows were fed Italian ryegrass hay at a calculated maintenance level. Two of 4 cows were subjected to 3 temperature treatments in the order of 18°, 26°, 32℃ at a relative humidity of 60%, while the other two were subjected to the same temperature treatments in the reverse order. Furthermore, the fasting metabolism of each cow was measured after the last temperature treatment.

Expt. 3 : Energy balances of 4 dry cows were measured to determine the energy requirements for maintenance. Two of 4 cows were fed Italian ryegrass hay (IH treatment) and other two were fed corn silage and 150 g soybean meal (CS treatment), at a maintenance feeding level. The cows were subjected to 3 temperature treatments of 18°, 26°, 32℃ at a relative humidity of 60%.

Expt. 4 : Energy balances of 4 lactating cows were measured to determine the energy requirements for production. Each cow was fed concentrate corresponding to 1/3 amount of 4% fat-corrected-milk yield, 4.5 kg beet pulp, 5 kg Italian ryegrass hay and corn silage *ad lib.* and was subjected to three temperature treatments of 18°, 26°, 32℃ at a relative humidity of 60%.

Results and discussion

1 Effect of environmental temperatures on net energy requirements for maintenance (NEm)

Treatment means for fasting heat production (FHP), urinary energy loss, NEm and physiological parameters in Expt. 1 and Expt. 2 are shown in Table 1.

The differences in FHP among the temperature treatments were not significant in Expt. 1 and Expt. 2. However, the FHP tended to increase slightly at 36℃ in Expt. 1. Rogerson (1960) reported that the FHP of cattle was not influenced by environmental temperatures in the range of 20°-40℃. Therefore, the FHP in the range of 18°-32℃ was considered to be constant. The value, 78.6 $kcal/kg^{0.75} \cdot$ day, will be used as the mean FHP value for subsequent analyses in this report.

Although the respiration rate during fasting increased at 32℃ in Expt. 2 and at 36℃ in Expt. 1, the body temperature was less than 38.5℃ and was controlled within a normal range. These findings imply that several mechanisms including respiratory function used to promote heat loss acted effectively because heat production, which acted as heat stress from the inner part of the body, was low during fasting. The absence of difference in the FHP among the temperature treatments was attributed to the fact that there was no increase in the metabolic

Table 1 Treatment means for fasting heat production, urinary energy loss, net energy requirement for maintenance (NEm)[Z] and physiological parameters in Expt. 1 and Expt. 2

Item	Treatment means			
	18℃	27℃	32℃	36℃
Fasting heat production (FHP ; kcal/kg$^{0.75}$·day)				
Expt. 1	80.3	77.8		81.9
Expt. 2	77.4		77.9	
Urinary energy loss (kcal/kg$^{0.75}$·day)				
Expt. 1	3.4	4.5		4.5
Expt. 2	2.5		2.6	
NEm (kcal/kg$^{0.75}$·day)				
Expt. 1	83.7	82.3		86.4
Expt. 2	79.9		80.5	
Body temperature (BT ; ℃)				
Expt. 1	38.20^{Aa}	38.30^{Ab}		38.80^{B}
Expt. 2	38.15		38.38	
Respiration rate/min.				
Expt. 1	10.8^{A}	17.3^{B}		57.3^{C}
Expt. 2	10.3^{A}		31.0^{B}	

[Z] NEm was calculated as the sum of the values of FHP and urinary energy loss during fasting.
Note : [a,b] Means within the same row with different superscripts differ ($P<.05$).
[A,B,C] Means within the same row with different superscripts differ ($P<.01$).

rate associated with an elevation of the body temperature (van't Hoff effect).

The values of NEm, calculated as the sum of the values of FHP and urinary energy loss during fasting, were 83.7, 82.3 and 86.4 kcal/kg$^{0.75}$· day at 18°, 27° and 36℃ in Expt. 1, respectively, and 79.9 and 80.5 kcal/kg$^{0.75}$· day at 18° and 32℃ in Expt. 2, respectively. There were no differences in the NEm between the temperatures of 18° and 27℃ in Expt. 1 and between those of 18° and 32℃ in Expt. 2. Also there were no differences in the NEm between Expt. 1 and Expt. 2 in the temperature rage of 18°-32℃. Therefore, the NEm values were considered to be almost constant in the range of 18°-32℃ and they tended to increase by about 5% at 36℃. Based on these findings, the mean value of NEm in the temperature range of 18°-32℃ was estimated at 82.1 kcal/kg$^{0.75}$· day. This value will be used for subsequent analyses in this report.

2 Effect of environmental temperatures and the type of roughage on metabolizable energy requirements for maintenance (MEm)

The results of the energy balance measurements in Expt. 2 and Expt. 3 are shown in Table 2.

Intakes of gross energy (GE) and metabolizable energy (ME) decreased at 26° or 32℃ due to the reduction in feed intake. The ME intake in the CS treatment was significantly greater than that in the IH treatment because the metabolizability of CS was significantly higher than that of IH. The difference in the ME intake between the two treatments was largest at 32℃.

Table 2 Energy balance measurements (kcal/kg$^{0.75}$·day) in Expt. 2. and Expt. 3

Item	Treatment means			Differences between IH and CS
	18℃	26℃	32℃	
Gross energy intake (GEI)				
Expt. 2	287.0^a	283.0^a	268.8^b	
Expt. 3 IH	258.4	251.1	182.0	NS^z
CS	281.7	259.1	238.3	
Metabolizable energy intake (MEI)				
Expt. 2	119.9^a	118.3^a	106.7^b	
Expt. 3 IH	106.8	98.0	70.6	*
CS	127.6	121.1	113.0	
Heat production (HP)				
Expt. 2	123.1^A	134.1^B	126.2^A	
Expt. 3 IH	121.4	121.1	111.6	NS
CS	128.4	119.5	126.6	
Energy retention (ER)				
Expt. 2	- 3.3	-15.8	-19.6	
Expt. 3 IH	-14.6	-23.2	-41.0	*
CS	- 0.9	1.6	-13.6	
ME/GE				
Expt. 2	0.418	0.418	0.396	
Expt. 3 IH	0.412	0.389	0.387	* *
CS	0.454	0.472	0.474	
HP/GEI (%)				
Expt. 2	42.9^A	47.5^B	46.8^B	
Expt. 3 IH	47.0^a	48.2^a	61.3^b	NS
CS	45.6	46.1	53.1	
ER/GEI (%)				
Expt. 2	- 1.1	- 5.7	- 7.2	
Expt. 3 IH	- 6.6^A	-10.2^A	-22.8^B	*
CS	- 0.8	0.0	- 6.4	
Body temperature (BT ; ℃)				
Expt. 2	38.32^a	38.47^a	39.13^b	
Expt. 3 IH	38.41	38.45	39.18	NS
CS	38.49	38.64	39.81	
Respiration rate (RR)/min.				
Expt. 2	17.0^A	25.4^A	51.0^B	
Expt. 3 IH	19.3	30.9	54.5	NS
CS	26.0	41.9	62.0	

^{z} Level of significance : * * $P<.01$; * $P<.05$; NS Not significant.

Note : ^{a,b} Means within the same row with different superscrits differ ($P<.05$).

^{A,B} Means within the same row with different superscripts differ ($P<.01$).

Heat production (HP) increased significantly at 26℃ compared with 18℃ in Expt. 2. Shibata and Mukai (1982) reported that the HP of cows without changes in feed intake increased at high environmental temperatures above 26℃. Since the feed intake was almost constant at 18° and 26℃ in Expt. 2, the rise in HP at 26℃ in Expt. 2 was in agreement with the results obtained by Shibata and Mukai (1982). On the other hand, the HP in Expt. 3 did not show any significant differences among the temperature treatments. However, the ratio of HP to GE intake increased significantly at 26° and 32℃ compared with 18℃ in Expt. 2 and increased at 32℃ in Expt. 3. Therefore, it is considered that HP may increase at high environmental temperatures if the GE intake remains constant.

Energy retention (ER) decreased with the rise in environmental temperature in Expt. 2. In Expt, 3, the ER of the IH treatment decreased with the rise in environmental temperature in the same way as in Expt. 2. The ER of the CS treatment, however, decreased only at 32℃ compared with 18° and 26℃. Although the ME intakes at 18 and 26℃ were almost the same in Expt. 2, the ER at 26℃ tended to decrease. These findings indicate that the MEm increased at 26℃ compared with 18℃. On the other hand, the ME intake at 26℃ decreased slightly compared with 18℃ in the CS treatment. The ER, however, at 26℃ did not decrease. These results show that the MEm at 26℃ was almost the same as that at 18℃. Therefore, it is considered that the increase in MEm at 26℃ was influenced by the type of roughage.

Treatment means for heat increment (HI) and MEm are shown in Table 3. HI was calculated as the difference between the values of HP and FHP (78.6 kcal/kg$^{0.75}$· day). MEm was calculated using the formula (NEm/ (efficiency of conversion of MEm to NEm) ; NEm= 82.1 kcal/kg$^{0.75}$· day). The efficiency of conversion (NEm/MEm) could be calculated based on the equation NEm/MEm=(ER − (−82.1))/(ME intake) for every temperature treatment.

Table 3 Treatment means for heat increment (HI)[Z] and metabolizable energy requirements for maintenance (MEm)[Y] in Expt. 2 and Expt. 3

Item	Treatment means			Differences between IH and CS
	18℃	26℃	32℃	
HI (kcal/kg$^{0.75}$·day)				
Expt. 2	45.2^{A}	55.5^{B}	47.6^{A}	
Expt. 3 IH	42.8	42.5	33.0	NS [X]
CS	49.8	40.9	48.0	
HI/MEI (%)				
Expt. 2	37.2^{a}	47.0^{b}	44.8	
Expt. 3 IH	39.8	44.1	47.6	NS
CS	39.6	34.1	43.0	
MEm (kcal/kg$^{0.75}$·day)				
Expt. 2	124.9	146.5	140.2	
Expt. 3 IH	129.9	136.6	141.0	
CS	129.0	118.8	135.4	

[Z] HI was calculated as the difference between the values of HP and FHP, and the FHP was assumed to be 78.6 kcal/kg$^{0.75}$·day.

[Y] MEm was calculated using the formula (NEm/(efficiency of conversion of MEm to NEm) ; NEm=82.1 kcal/kg$^{0.75}$·day). The efficiency of conversion (NEm/MEm) could be calculated by the equation NEm/MEm=(ER−(−82.1))/(ME intake).

[X] Level of significance : NS Not significant.

Note : [a,b] Means within the same row with different superscripts differ ($P<.05$).

[A,B] Means within the same row with different superscripts differ ($P<.01$).

Although the HI significantly increased at 26℃ compared with 18℃ in Expt. 2, there were no significant differences among the temperature treatments in Expt. 3. Since the amount of feed intake was not constant in Expt. 2 and Expt. 3, HI was expressed by using the ratio of HI to ME intake to eliminate the difference in feed intake. The ratio of HI to ME intake was higher at 26° and 32℃ compared with 18℃ in Expt. 2. In Expt. 3, the ratio of the IH treatment started to increase from 26℃ in the same way as in Expt. 2 and the ratio of the CS treatment increased only at 32℃. These results suggest that the HI of cows without changes in the ME intake may increase at high environmental temperatures and that the increase in HI may be affected by the type of roughages. The ratios of HP or HI to energy intake increased at high environmental temperatures since the metabolic rate increased due to the elevation of the body temperature (Hales and Findlay, 1968), and also, the energy was used to increase heat dissipation through several mechanisms including respiratory functions. Although it was recommended that diets administered during periods of high temperature should give a lower HI in order to minimize heat stress from the inner part of the body (Brokken, 1971 ; Shibata and Mukai, 1977), it was considered that the present data were also in agreement with this requirement.

The MEm in Expt. 2 started to increase at 26℃. In Expt. 3, the MEm in the IH treatment also started to increase at 26℃. The MEm in the CS treatment, however, increased only at 32℃. Since the metabolizability (q) of Italian ryegrass hay used in Expt. 2 was almost the same as that in the IH treatment in Expt. 3 (q=0.4), the mean MEm of cows given Italian ryegrass hay was calculated at 18°, 26° and 32℃. The mean values for MEm were 127, 143 and 141 kcal/kg$^{0.75}$· day at 18°, 26° and 32℃, respectively. Since the MEm in the CS treatment did not increase at 26℃ unlike in the IH treatment, the mean MEm of 18° and 26℃ was calculated as the value that was not affected by the environmental temperature (124 kcal/kg$^{0.75}$· day). Leahay *et al.* (1973) reported that the values for MEm of cows given hay and urea-treated corn silage were 132 and 122 kcal/kg$^{0.75}$· day, respectively. The value for MEm not affected by the environmental temperature in this report agreed well with the value reported.

The value for MEm in Expt. 2 was about 15% higher at 26° and 32℃ compared with 18℃. The value for MEm tended to be higher by about 5 and 9% at 26° and 32℃, respectively compared with 18℃ in the IH treatment and to be about 9% higher at 32℃ compared with 18° and 26℃ in the CS treatment. The mean value for MEm in cows given Italian ryegrass hay, with a metabolizability of about 0.4, was about 10% higher at 26° and 32℃ compared with 18℃. The National Research Council (NRC, 1981) reported that energy requirements for the maintenance of lactating cows increased to 104 and 111 at 25° and 30℃, respectively when the energy requirements for maintenance at 10-20℃ were assumed to be 100. The rate of increase in the MEm from 18℃ to 32℃ in these experiments was almost the same as that reported by the NRC. However the increase at 26℃ was obtained only in cows given Italian ryegrass hay. These results suggest that the increase in the MEm at high environmental temperatures was affected by the type of ration and the increase in the MEm of cows given low HI roughage tended to be lower. Therefore, it is suggested that dry dairy cows should be given 10% more MEm under high temperature conditions compared with the thermoneutral zone and the ration should give a lower HI to minimize the increase in MEm.

3 Effect of environmental temperature on metabolizable energy requirements of lactating cows.

The results of energy balance measurements in Expt. 4 are shown in Table 4.

Intakes of GE and ME slightly decreased at 26℃ and significantly decreased at 30℃ compared with 18℃. The metabolizability increased with the rise in the environmental temperature. The increase in the metabolizability was probably due to the reduction in roughage consumption at high temperatures. Milk energy output decreased at 30℃ due to the

Table 4 Results of energy balance measurements (kcal/$kg^{0.75}$·day) in Expt. 4

Item	Treatment means		
	18℃	26℃	30℃
GEI[Z]	623.2^{A}	585.9^{A}	436.0^{B}
MEI[Z]	344.0^{A}	330.3^{A}	260.1^{B}
Milk energy (Milk)	148.4^{A}	145.9^{A}	116.8^{B}
ER[Z]	-19.0	-19.9	-38.5
EB[Y]	129.4^{A}	126.0^{A}	78.3^{B}
ME/GE	0.552^{A}	0.564^{B}	0.598^{C}
Milk/GEI (%)	23.8^{A}	24.8^{a}	26.8^{Bb}
ER/GEI (%)	-3.1^{a}	-3.3^{a}	-9.1^{b}
EB/GEI (%)	20.8	21.5	17.6
EB/MEI (%)	37.6^{a}	38.1^{a}	29.6^{b}
EB/(MEI−MEm[X]) (%)	57.2	59.1	—
EB/(MEI−1.1×MEm) (%)	—	—	58.7

[Z] See Table 2.
[Y] EB ; Energy balance=Milk+ER
[X] MEm was calculated as (NEm/(efficiency of ME utilization for maintenance (km)) ; NEm=82.1 kcal/$kg^{0.75}$·day). The efficiency (km) was derived from the equation of km=0.35×(metabolizablility)+0.503 (ARC, 1980).
Note : [a,b] Means within the same row with different superscripts differ ($P<.05$).
[A,B,C] Means within the same row with different superscripts differ ($P<.01$).

reduction in the energy intakes. However the ratio of milk energy output to GE intake increased at 30℃. This increase in the GE utilization for milk production was attributed to the utilization of body tissue energy at 30℃ since energy mobilization from body tissues at 30℃ was twice as large as that at 18° and 26℃. Energy balance (EB), which was represented by the sum of the milk energy output and ER, at 30℃ decreased by 60% of that at 18° and 26℃. The ratio of EB to GE intake tended to decrease at 30℃ and the ratio of EB to ME intake significantly decreased at 30℃. These results suggest that the partition of GE to milk plus body tissue energy decreased at 30℃ and the efficiency of conversion of ME to milk plus body tissue energy decreased at 30℃.

The ratio of EB to ME intake above MEm was calculated for 18° and 26℃ to estimate the energy requirements for production. However, since the MEm of the dry cows increased by about 10% at 32℃, the ratio at 30℃ was calculated by using the formula EB/(ME intake −1.1×MEm). MEm was calculated from NEm (82.1 kca/$kg^{0.75}$· day) and the efficiency of ME utilization for maintenance (km), NEm/km. The metabolizability significantly changed with the environmental temperature and the metabolizability of ration in Expt. 4 was different from that in Expt. 2 and Expt. 3. Therefore, the equation described below was used to derive the km.

km=0.35×(metabolizability)+0.503 (ARC, 1980).

Since the ratio did not change appreciably with the environmental temperature, it is suggested that the energy requirements of lactating cows increased at high environmental temperatures and the increase was mainly caused by the increase in the MEm.

Conclusion

ME requirements of dairy cows increased by about 10% at high environmental temperatures. The increase was mainly attributed to the increase in MEm and may be influenced by the type of ration. The increase in MEm of cows given low HI ration was lower. Therefore, dairy cows should be given low HI ration and 10% more ME for maintenance under high temperature conditions compared with the thermo-neutral zone. Moreover, since the energy requirements of dairy cows increase in spite of the reduction in voluntary feed intake under high temperature conditions, the ration should have a high palatability and high energy content to meet the increased requirements.

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Discussion

Ku Vera, J. C. (Mexico) : Was the increase in heat increment in the corn silage diet compared with the hay diet due mainly to the energy spent in activities such as eating, ruminating or to other components of heat increment? Probably the increase in the respiration rate at high temperatures (36℃) was also a contributing factor.

Answer : The rate of heat increment to ME intake increased under high temperature conditions. However the increase in cows fed corn silage was evident at higher environmental temperatures than in cows fed Italian ryegrass hay. Heat increment is influenced by many factors, including eating, rumination, metabolism of VFA, fat, carbohydrate, protein, etc. Of these factors, the metabolism of VFA may be the most important one. The increase in heat increment under high temperature conditions is due to the effect of the increase of the body temperature on the metabolic rate and energy expended in ridding the body of excess heat load.

Shibata, M. (Japan) : You suggested a 10% increase in energy requirement under high temperature conditions. Could you comment on the design of a feeding program in a hot environment or in tropical countries?

Answer : The ration should have a high palatability and high energy content to meet the increased requirements. The administration of concentrate is more important in a hot environment than in an optimum environment. However, since grains are important as human food, their use for animal feed may be a major constraint in some countries.

Lopes, H. O. S. (Brazil) : Comment : The conclusions of your studies are highly relevant to tropical countries since you had access to sophisticated equipment (climatic chambers) which can simulate high temperatures as those observed in the tropics.

Haryanto, B. (Indonesia) : I would like to add that in Indonesia we are also trying to evaluate the energy requirements for cattle, sheep and goats. It appears that these animals require about 20% energy over the NRC standards.

Answer : Thank you for your information. In this study it was shown that the MEm of cows fed a ration with low metabolizability increased more under high temperature conditions. These observations suggest that the rate of increase is not constant and further studies should carried out to analyse the rates of increase of energy requirements in dairy cows fed many types of rations.