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Energy Requirements and Feed of Dairy Cows under High Temperature Conditions

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Abstract
The gross efficiency of energy consumed and the productivity of dairy cows are affected by heat stress. In this report attempts were made to examine the energy requirements and feeding method of Holstein cows under high temperature conditions. To achieve this objective, energy balance trials were conducted under a temperature range of 18-36 ℃ using dry and lactating cows. The net energy requirement for maintenance of dry cows was 82.1 kcal/kg0.75•day in the range of 18-32℃ and it tended to increase by 5% at 36℃. The metabolizable energy requirements for maintenance (MEm) increased by 10% at 26 and 32℃. The increase in MEm tended to be lower in the case of highly metabolizable diets. The energy requirements of lactating cows increased under high temperature conditions. This increase seemed to be mainly caused by the increase in the MEm. There were no significant differences in the efficiency of conversion of ME partitioned to milk and body tissue among temperatures, and the efficiency was about 61%. It was observed that when the metabolizability of diets increased, the ME intake and the partition of gross energy to production in lactating cows increased whereas the heat increment which acted as a promoter of heat stress from the inner part of the body at high environmental temperatures decreased.

Discipline: Animal industry
Additional key words: energy utilization, energy partition, heat increment, metabolizability of diets

Introduction

Dairy cattle performance is affected by heat stress[8] because dairy cattle for which it is difficult to lose heat will decrease heat production by reducing feed intake, resulting in a reduced milk production and growth. Moreover, even by forced feeding through a rumen fistula, milk yield of stressed dairy cows (32°C) was 10% below that of controls maintained at 18°C[11]. Milk energy decreased about twice as much as the digestible energy intake[6]. Therefore, it was considered that the energy requirements of lactating cows increased at high temperatures, and also, that the efficiency of conversion of feed energy units to production energy units decreased during heat stress[6,10,11]. However, there are few quantitative studies on the effect of environmental temperatures and the type of ration on energy requirements and energy partition in dairy cows.

This report deals with the effects of environmental temperatures on the energy metabolism of dry and lactating cows with a view to identifying the energy requirements and the quality of feed, which should be fed to dairy cows, in a hot environment.

Net energy requirements for maintenance (NEm) under high temperature conditions

The influence of constant high temperatures on fasting metabolism was examined in using dry non-pregnant Holstein cows housed in the energy metabolism laboratory of the Kyushu National Experiment Station. Relative humidity was adjusted to 60%. Before fasting, cows were fed Italian ryegrass hay at a calculated maintenance level.

Table 1 shows the fasting heat production (FHP), urinary energy loss, NEm, body temperature (BT) and respiration rate (RR) in dry cows during fasting at 18, 27, 32 and 36°C. The FHP at 18, 27 and 32°C was similar. The FHP tended to increase at 36°C and was 78.6 kcal/$kg^{0.75}$•day in the range of 18–32°C.

Although the RR during fasting increased at 27°C,

Table 1. Fasting heat production, urinary energy loss, net energy requirements for maintenance (NEm)[1)] and physiological parameters at 18, 27, 32 and 36°C in the experiments using dry cows

Item	Environmental temperature (°C)			
	18 (n = 6)	27 (n = 4)	32 (n = 2)	36 (n = 4)
Fasting heat production (FHP) (kcal/kg$^{0.75}$·day)	79.3	77.8	77.9	81.9
Urinary energy loss (kcal/kg$^{0.75}$·day)	3.1	4.5	2.6	4.5
NEm (kcal/kg$^{0.75}$·day)	82.4	82.3	80.5	86.4
Body temperature (BT) (°C)	38.18^a	38.30^b	38.38^b	38.8^c
Respiration rate (RR) (/min)	10.6^a	17.3^b	31.0^c	57.3^d

1): NEm was calculated as the sum of the values of FHP and urinary energy loss during fasting (cited from ARC, 1980[1)]).
a, b, c, d: Means within the same row with different superscripts were significantly different ($P < 0.05$).

the BT was less than 38.5°C, corresponding to a normal range. These results suggest that several mechanisms including respiratory function effectively promote heat loss because heat production, which acted as heat stress from the inner part of the body, was low during fasting.

The values of NEm were 82.4, 82.3, 80.5 and 86.4 kcal/kg$^{0.75}$·day at 18, 27, 32 and 36°C, respectively. The values of NEm at 18, 27 and 32°C were similar but tended to increase by 5% at 36°C. Based on these results, the NEm value was found to be 82.1 kcal/kg$^{0.75}$·day in the range of 18–32°C.

Effect of environmental temperature and feed on metabolizable energy requirements for maintenance (MEm)

Energy balance trials were conducted at temperatures of 18, 26 and 32°C using dry non-pregnant Holstein cows which received two kinds of feeds at a calculated maintenance level, namely Italian ryegrass hay and corn silage with the addition of 150 g soybean meal. Relative humidity was adjusted to 60%.

Table 2 shows the metabolizability(q) of feed, metabolizable energy (ME) intake, energy retention (ER), the ratio of heat increment (HI) to ME intake and MEm at 18, 26 and 32°C. The ME intake was low at 32°C due to the reduction in feed intake. The ME intake of cows fed corn silage was greater than that of cows fed Italian ryegrass hay, presumably due to the difference in q. The difference in the ME intake between the two types of feed was the largest at 32°C.

In the case of Italian ryegrass hay feeding, the ME intakes at 18 and 26°C were almost similar, but the ER was considerably different. It appears that the decrease of ER had started at 26°C. Therefore the MEm value at 26°C was higher than that at 18°C. On the contrary, results for the MEm value and the ER in the case of corn silage feeding were opposite, suggesting that the increase in MEm at 26°C is influenced by the kind of feed.

The ratio of HI to ME intake was higher at 26 and 32°C compared with that at 18°C in dry cows fed Italian ryegrass hay. In dry cows fed corn silage, the ratio increased only at 32°C. These results suggested that the HI increased at high environmental temperatures without changes in the ME intake but that the increase was affected by the type of feed.

Table 3 lists the physiological parameters at 18, 26 and 32°C. The body temperature (BT) and the respiration rate (RR) increased markedly at 32°C. Hales and Findlay[3)] reported that the metabolic rate increased due to the elevation of the body temperature (van't Hoff effect). The increase in RR indicated that heat dissipation increased through the body

Table 2. Metabolizability (q) of feed, metabolizable energy (ME) intake, ratio of heat increment (HI)[1)] to ME intake and energy requirements for maintenance (MEm)[2)] at 18, 26 and 32°C in the experiments using dry cows

Feed	Environmental temperature (°C)		
	18	26	32
q of feed			
Italian ryegrass hay	0.416	0.408	0.393
Corn silage & soybean meal	0.454	0.472	0.474
ME intake (kcal/kg$^{0.75}$·day)			
Italian ryegrass hay	115.5	111.5	94.7
Corn silage & soybean meal	127.6	121.1	113.0
Energy retention (ER) (kcal/kg$^{0.75}$·day)			
Italian ryegrass hay	−7.1	−18.3	−26.7
Corn silage & soybean meal	−0.9	−1.6	−13.6
HI/ME intake (%)			
Italian ryegrass hay	38.1	46.0	45.7
Corn silage & soybean meal	39.6	34.1	43.0
MEm (kcal/kg$^{0.75}$·day)			
Italian ryegrass hay	126.6	143.3	140.5
Corn silage & soybean meal	129.0	118.8	135.4

1): 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.

2): 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).

Table 3. Physiological parameters at 18, 26 and 32°C in the experiments using dry cows

Feed	Environmental temperature (°C)		
	18	26	32
Body temperature (°C)			
Italian ryegrass hay	38.35^{a}	38.46^{a}	39.15^{b}
Corn silage & soybean meal	38.49	38.64	39.81
Respiration rate/min			
Italian ryegrass hay	17.8^{a}	27.2^{a}	52.2^{b}
Corn silage & soybean meal	26.0	41.9	62.0

a, b: Means within the same row with different superscripts were significantly different ($P<0.05$).

surface and respiratory functions[4)]. Therefore, the increase in the ratio of HI to ME intake at 32°C was caused by the increase in the metabolic rate and energy used for heat dissipation.

The MEm value of dry cows fed Italian ryegrass hay started to increase at 26°C. The MEm value of dry cows fed corn silage did not increase at 26°C unlike that of the cows fed Italian ryegrass hay. The mean MEm value of dry cows fed corn silage at 18 and 26°C (124 kcal/kg$^{0.75}$·day) could be considered as the value that was not affected by the environmental temperature. The value was in agreement with the results reported by Leahay et al.[5)], showing that the MEm value of cows given urea-treated corn silage was 122 kcal/kg$^{0.75}$·day.

The MEm of dry cows given Italian ryegrass hay was 12% higher at 26 and 32°C than at 18°C. The MEm tended to increase by 9% at 32°C compared with 18 and 26°C when corn silage was offered. The National Research Council[7)] reported that the MEm of lactating cows was 104 and 111 at 25 and 30°C, respectively, when the MEm at 10–20°C was assumed to be 100. The rate of increase in the MEm from 18 to 32°C in this report was similar to that reported by the NRC. However the increase at 26°C was observed only in cows given Italian ryegrass hay. These results suggested that the increase in the MEm at high environmental temperatures was affected by the kind of feed and the increase tended to be lower when low HI feed was offered. Therefore, it is suggested that under high temperature conditions for dry dairy cows the MEm value should be 10% higher compared with the thermoneutral zone and the feed should give a lower HI to minimize the increase in MEm. These results are in agreement with the recommendation[2,9] that feed administered during periods of high temperature should give a lower HI in order to minimize heat stress from the inner part of the body.

Energy requirements and partition in lactating cows under high temperature conditions

Energy balances of lactating non-pregnant Holstein cows were calculated to determine the effect of high constant temperature on the energy requirements and partition. Cows were fed one of three diets as follows: HQ diet (Italian ryegrass hay (IRH) : concentrate ratio = 3 : 7), MQ diet (concentrate corresponding to 1/3 amount of 4% fat-corrected-milk yield, 4–5 kg beet pulp, 5 kg IRH, corn silage *ad libitum*) and LQ diet (IRH : concentrate ratio = 7 : 3).

Table 4 shows the q of diets, ME intake, ratio of HI to ME intake and energy balance of lactating cows used in the experiment. The ME intake slightly decreased at 26°C and markedly decreased at 30°C compared with that at 18°C. The ratio of energy balance (EB), which was represented by the sum of the milk energy output and energy retention (ER), to gross energy (GE) intake tended to decrease at 30°C. The highest ME intake and ratio of EB to GE intake at 30°C were observed in the lactating cows fed HQ diet. These results suggested that the partition of GE to milk and body tissues decreased at 30°C and the efficiency of conversion of GE to milk and body tissues decreased at 30°C. However, if lactating cows were fed a diet with higher q, the reduction in production would be minimized.

Table 5 shows the efficiency of ME utilization for milk production and energy retention at 18, 26 and 30°C. The ratio of EB to ME intake above MEm was calculated for the temperatures of 18 and 26°C to estimate the energy requirements for production. However, since the MEm of the dry cows increased by about 10% under high temperature conditions, the ratio at 26 and 30°C was recalculated by using the formula EB/(ME intake – 1.1·MEm).

Table 4. Metabolizability (q) of diets, ME[1)] intake, ratio of HI[1)] to ME intake and energy balance[2)] at 18, 26 and 30°C in the experiments using lactating cows

Item[3)]	Environmental temperature (°C)		
	18	26	32
q of diets			
HQ diet	0.552	0.548	0.610
MQ diet	0.552^a	0.564^a	0.598^b
LQ diet	0.512	0.499	0.511
ME intake (kcal/kg$^{0.75}$·day)			
HQ diet	365.4	306.1	283.4
MQ diet	344.0^a	330.3^a	260.1^b
LQ diet	293.9^a	276.7^a	242.4^b
HI/(ME intake) (%)			
HQ diet	37.2	39.2	36.5
MQ diet	39.6	38.0	40.0
LQ diet	39.9	37.6	38.1
Energy balance (EB) (% of gross energy consumed)			
HQ diet	22.8	18.6	20.3
MQ diet	20.8	21.5	17.6
LQ diet	17.0	16.9	14.8

1): a, b; Means within the same row with different superscripts were significantly different ($P<0.05$).

2): EB is the sum of milk energy and energy retention.

3): HQ, MQ and LQ diets; Refer to the text.

Table 5. Efficiency of ME utilization for milk production plus energy retention at 18, 26 and 30°C in experiments using lactating cows

Item [1]	Environmental temperature (°C)		
	18	26	32
HQ diet			
EB/ME intake (%)	41.2	33.7	33.1
EB/(ME intake - MEm) (%)	60.8	57.5	61.1
EB/(ME intake - 1.1·MEm) (%)	-	61.4	65.6
MQ diet			
EB/ME intake (%)	37.6[a]	38.1[a]	29.6[b]
EB/(ME intake - MEm) (%)	57.2	59.1	53.0
EB/(ME intake - 1.1·MEm) (%)	-	62.7	58.7
LQ diet			
EB/ME intake (%)	33.2	33.8	29.0
EB/(ME intake - MEm) (%)	56.2	60.1	58.2
EB/(ME intake - 1.1·MEm) (%)	-	65.3	64.6

1): HQ, MQ and LQ diets; Refer to the text.
EB, a, b; Same as in Table 4.
MEm; MEm was calculated as (NEm/km (efficiency of ME utilization for maintenance), NEm = 82.1 kcal/$kg^{0.75}$·day).
The efficiency (km) was derived from the equation of km = 0.35 q + 0.503 (cited from ARC, 1980[1]).

The ratio of EB to ME intake decreased at 30°C compared with 18°C. Under high temperature conditions, the efficiency of conversion of ME to milk and body tissues seemed to decrease and the energy used for heat dissipation seemed to increase. Consequently, the ME requirement under high temperature conditions is likely to be higher for lactating cows to maintain the same production in the thermoneutral zone. The ratio of EB to ME used for milk production plus energy retention did not change appreciably with the environmental temperatures. The mean efficiency of ME utilization for milk and energy retention was almost constant at 61% in the range of 18-32°C. Therefore the energy requirements of lactating cows increased at high environmental temperatures and this increase seemed to be mainly caused by the increase in the MEm.

Feed of dairy cows under high temperature conditions

The results presented above suggest that if the q value of diets could increase, the ME intake and the partition of GE to production may increase. The heat increment and the increase in MEm under high temperature conditions may decrease. Therefore, if dairy cows are fed a diet with high q under high temperature conditions, production may increase. The q value was obtained by dividing the ME value of the diet by the GE value. Although it is difficult to measure directly the ME value of the diet, it could be estimated by using the chemical composition or digestible nutrients. As a result of a comparative evaluation of several equations for predicting the ME (Mcal/kg DM) contents of diets for cattle, it was suggested that the following two equations could be used for predicting the ME contents of diets[4].

$$ME = -1.312 + 0.0603 \cdot CP + 0.0500 \cdot Oa + 0.0215 \cdot Ob + 0.0505 \cdot NCWFEe,$$
$$ME = -0.330 + 0.958 \cdot DE,$$

where, CP: crude protein (%DM), Oa: high digestible fraction of organic cell wall (organic a, %DM), Ob: low digestible fraction of organic cell wall (organic b, %DM), NCWFEe: nitrogen cell wall free extract obtained by enzymatic analysis (%DM), DE: digestible energy (Mcal/kg DM).

Therefore, the q value of diets could be calculated by dividing the estimated ME value by the measured GE value.

Moreover, since the MEm increases in spite of the reduction in feed intake under high temperature conditions, the ration should have a high palatability and high energy content to meet the increased requirements. In experiments using lactating cows, the degree of reduction in the dry matter intake under high temperature conditions decreased in the order of Italian ryegrass hay, corn silage, beet pulp, concentrate. The concentrate intake could decrease by 30 to 70% at 30°C compared with 18°C when the ratio of concentrate to total dry matter intake was 65%. Content of total digestible nutrients of calcium soap of fatty acids made of palm oil was reported to be 170%[4]. These findings indicate that under high temperature conditions, the use of corn silage, beet pulp and concentrate and fatty acids may enable to alleviate the reduction in energy intake.

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