Mineral Requirement of Dairy Cows under High Temperature Conditions

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Abstract

Heat stress in summer alters mineral needs in ruminants. The requirements of major minerals (Ca, P, Mg, Na and K) and trace elements (Fe, Zn, Cu, Mn, Se, Mo and Co) in dairy cows under high temperature conditions were evaluated based on balance and feeding trials. Mineral requirements for maintenance in dairy cows increased at high temperatures, since mineral excretion during fasting was enhanced above 27℃. Calcium, P, Mg, and Na contents in milk decreased at high temperatures, while the contents of other elements were not affected by heat stress.

Calcium and P balances in lactating cows were negative when milk production was high under optimum temperature conditions. Major mineral and trace element requirements in lactating cows under optimum temperature conditions which were calculated from 24 balance trials at 18℃ were almost similar to the estimates of NRC standard, except for the Ca, Mn and Co requirements. Since the intake and apparent absorption of major mineral and trace elements in lactating cows were depressed by heat stress, it is suggested that the mineral requirements in lactating cows increase under high temperature conditions.

Introduction

Environment directly and indirectly influences the productivity of dairy cattle. Heat stress in summer reduces the feed intake, milk yield and milk composition of dairy cows, and alters the mineral needs (Collier *et al*., 1982 ; Beede and Collier, 1986). Also, heat-stressed dairy cows may exhibit increased sodium (Na) and potassium (K) requirements, since the Na and K loss via the skin, saliva, and urine has been reported to increase in a hot environment (ARC, 1980 ; Collier *et al*., 1982). However, the other mineral requirements in dairy cows have not been well determined at high temperatures.

Numerous experiments showed that it is possible to increase the productivity of heat-stressed cattle with the increase of the amounts of dietary Na and K, which affected milk yield, milk composition, and physiological responses of dairy cows (Collier *et al*., 1982 ; Beede and Collier, 1986). In this report, the requirements of major minerals, such as calcium (Ca), phosphorus (P), magnesium (Mg), Na and K, and trace elements, such as iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), selenium (Se), molybdenum (Mo) and cobalt (Co), in Holstein dairy cows under high temperature conditions were evaluated based on balance and feeding trials in order to enhance the productivity of heat-stressed cattle.

Mineral requirement for maintenance and lactation at high temperatures

Factorial method has been used to estimate the mineral requirements of dairy cows

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(ARC, 1980 ; NRC, 1988). In this report, the net requirement for maintenance at high temperatures was estimated from mineral excretion during fasting in controlled climatic rooms (Kume *et al.*, 1987 ; Kume, 1989), and the net requirement for lactation was calculated from the mineral composition in milk under actual conditions and/or in climatic rooms (Kume *et al.*, 1989a ; 1989b ; 1990 ; 1991).

Major route of endogenous loss for most minerals, except for K and Na, is through the feces under optimum temperature conditions (ARC, 1980). Since fecal excretion of Ca, P and Mg at 18℃ during fasting was slightly lower than the endogenous fecal loss of ARC (Table 1), it is assumed that the values obtained were the net minimum requirements of Ca, P and Mg for maintenance. Also, Ca, P and Mg requirements for maintenance may increase at high temperatures, since the fecal excretion of Ca, P and Mg at 27℃ during fasting was 10 to 20 % higher than that at 18℃. The reason for the high urinary P excretion during fasting is not clear, but the considerable increase in the urinary P excretion above 27℃ may be associated with the increase of P requirement.

Trace element requirements for maintenance as well as Ca, P and Mg may increase at high temperatures, although there are limited data on the endogenous loss of trace elements. In addition, Na and K losses via the skin, saliva and urine were larger at high temperatures, compared with the other mineral losses (Collier *et al.*, 1982). Therefore, it is suggested that the net mineral requirements for maintenance increase under high temperature conditions.

Table 1 Comparison of mineral excretion in 4 cows during fasting and estimates of endogenous loss (mg/kg body wt per day)

	Treatment means			Treatment	Endogenous loss	
	18℃	27℃	36℃	effect	ARC	NRC
	------ During feeding[Z] ------					
Ca excretion						
feces	48.3	49.0	38.8	NS		
urine	2.8	0.8	0.4	*		
P excretion						
feces	22.0	21.3	19.2	NS		
urine	0.3	0.2	0.3	NS		
Mg excretion						
feces	12.2	13.0	12.0	**		
urine	3.2	3.6	2.6	NS		
	------ During fasting[Y] ------					
Ca excretion						
feces	11.2	13.4	13.7	NS	(15.7)	---
urine	0.1	0.1	0.1	NS	(0.8)	---
total	11.3	13.5	13.8	NS	16.0	15.4
P excretion						
feces	7.6	8.6	9.4	NS	10.0	---
urine	4.3	7.2	7.1	NS	2.0	---
total	11.9	15.8	16.5	NS	12.0	14.3
Mg excretion						
feces	2.3	2.8	3.0	NS	3.0	---
urine	0.1	0.1	0.1	NS	---	---
total	2.4	2.9	3.1	NS	3.0	---

[Z] Collected the day before fasting.
[Y] Collected 68-116 h after last food.
Note : ** P<.01, * P<.05, NS Not significant.

Table 2 Comparison of the values of mineral composition in milk

	Environmental temperature^{Z}		Mineral in milk	
	Optimum^{Y}	Hot^{X}	ARC	NRC
Number of samples	184	99		
Milk yield, kg/d	21.9± 5.7	23.2± 3.6*		
Milk composition				
Total solid, %	12.6± 0.7	12.1± 0.7**		
Ca, mg/100ml	120 ±11	114 ±10**	113	122^{W}
P, mg/100ml	90 ± 7	85 ± 7**	90	99^{W}
Mg, mg/100ml	10.1± 1.1	9.3± 0.9**	12.5	15
Na, mg/100ml	40 ± 5	37 ± 5**	58	---
K, mg/100ml	162 ±14	160 ±14	158	150

^{Z} Mean monthly temperature, ^{Y} 5.1-20.1℃, ^{X} 22.5-27.2℃, ^{W} 4% FCM.
Note : ** P<.01, * P<.05.

Mineral composition in milk varies with several factors, including individual, breed, parity, feed offered, time post-partum, etc. Heat stress in summer reduced the Ca, P, Mg and Na contents in milk (Table 2) and the ratios of these contents in a hot environment compared to the optimum environment were 92.1 to 95.0%. Also, the Ca, P and Mg contents in milk decreased throughout the lactation period by heat stress and the reduced rates of these contents were highest at higher monthly temperatures such as above 26℃ during July to August.

The reduced contents of Ca, P and Mg in milk may be due to the delayed availability of these minerals, since the Ca, Pi and Mg concentrations in serum decreased linearly with the corresponding minerals in milk at high temperatures. However, it remains to be determined whether the K and trace element contents in milk were affected by heat stress. Thus, the net requirements of Ca, P, Mg and Na for lactation may decrease under high temperature conditions.

Mineral requirement of lactating cows under optimum temperature conditions

The assessment of mineral requirement in dairy cows under optimum temperature conditions is needed firstly to clarify the effect of heat stress on the mineral requirement. It has been reported that the upper critical temperature for lactating cows is 25℃ and significant changes in various physiological processes will not usually occur within the range of 5° to 25℃ (NRC, 1981 ; Collier *et al.*, 1982). In this report, mineral requirements of lactating cows under optimum temperature conditions were calculated from balance trials at 18℃ in controlled climatic rooms or feeding trials under actual conditions (Kume, 1989 ; Kume *et al.*, 1991).

Mineral needs for dairy cows are markedly enhanced immediately after parturition, since large amounts of minerals are secreted in milk. Cows with high milk production are often unable to consume enough feed to prevent some loss of body energy, protein and minerals in early lactation, because the maximum dry matter intake usually lags behind the peak milk yield (NRC, 1988). Therefore, mineral requirements in lactating cows should be evaluated at each stage of the lactation period, especially at the stage of early lactation.

Braithwaite (1983a, 1983b) reported that ewes, despite an abundant dietary intake of Ca and P, are unable to absorb enough Ca and P during late pregnancy and early lactation to meet the high demands and have to mobilize skeletal mineral reserves. In this report, Ca and

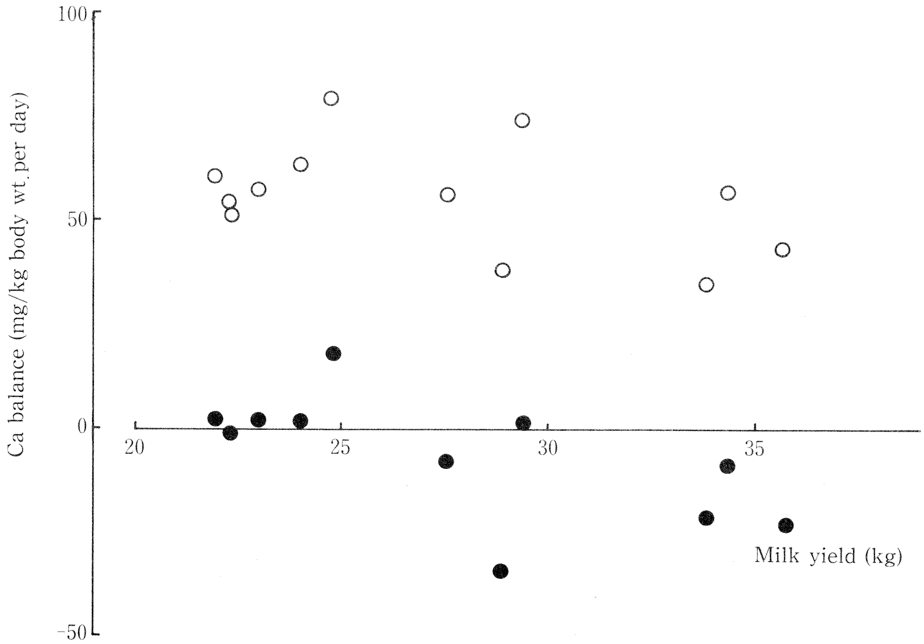

Fig. 1 Relationship between milk yield and Ca absorption (○) or Ca retention (●) in lactating cows at 18℃.

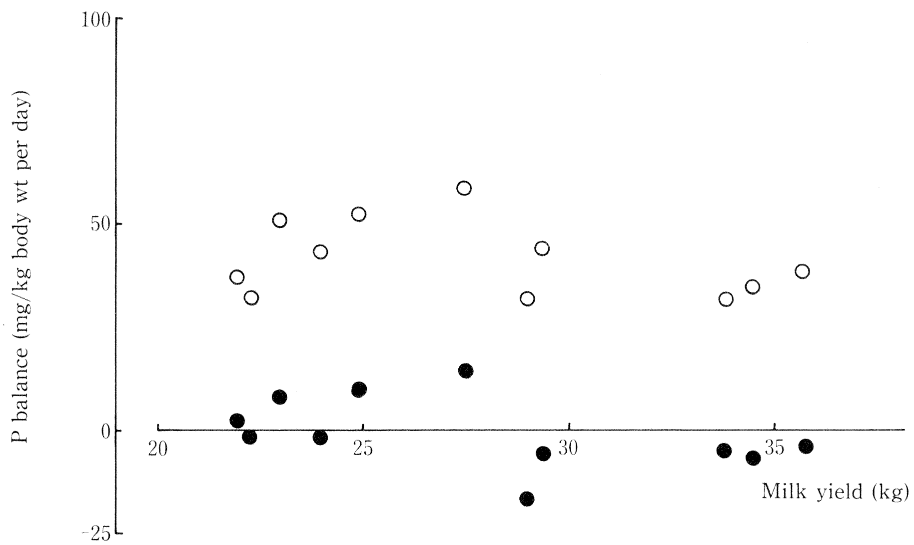

Fig. 2 Relationship between milk yield and P absorption (○) or P retention (●) in lactating cows at 18℃.

P retentions in lactating cows were negative at the stage of high milk production, even though the Ca and P supply for the cows was sufficient (Fig. 1 and 2). The results obtained indicated that Ca and P stored in the bones of cows with high milk production were utilized for meeting their requirement at the stage of early lactation, because the absorption of Ca and P appears to be limited for high milk production such as above 31 kg/day (600 kg body weight). Also, there may be a negative retention in Zn and Se when the milk production is high, unlike in other minerals. It is suggested that, at the stage of mid- to late lactation, most of Ca, P, Zn and Se was required for lactating cows to replenish the lost reserves in the body.

Dietary mineral requirements in lactating cows under optimum temperature conditions were calculated from 24 balance trials at 18℃ and 60% relative humidity for 2 weeks per trial (Table 3). Daily milk yields of the cows ranged from 20.5 to 35.8 kg (Mean ± S. D. : 27.0 ± 4.5) and body weights from 497 to 710 kg (Mean ± S. D. : 584 ± 57). Compared to the estimates of dietary mineral requirements in ARC (1980), JFS (1987) and NRC (1988), our estimates were almost similar to those of the NRC or JFS, although the Ca, Mn and Co requirements in our estimates were higher. Also, the estimates of Zn, Cu and Co requirements calculated from feeding trials were slightly lower than those from balance trials, partly because daily milk yields of lactating cows in feeding trials were below 20 kg at the time of slaughter.

Mineral requirement of lactating cows under high temperature conditions

Heat stress in the summer environment in Japan adversely affects the feed intake, milk yield and milk composition in lactating cows (Shibata, 1983). Mineral needs for lactating cows vary with the changes in the milk yield and milk composition in a hot environment. In this report, the mineral requirement of lactating cows under high temperature conditions was estimated from balance trials in controlled climatic rooms (Kume *et al.*, 1987 ; 1991) and feeding trials under actual conditions (Kume *et al.*, 1989a ; 1989b ; 1990).

Table 3 Comparison of the estimates of dietary mineral requirement in lactating cows[Z] under optimum temperature conditions

	ARC (1980)	JFS (1987)	NRC (1988)	Kume et al.[Y] (1991)
		% on dry basis		
Ca	0.34	0.57	0.58	0.73
P	0.31	0.38	0.37	0.39
Mg	0.17	0.16	0.20	0.23
Na	0.12	0.18	0.18	0.16
K	0.74	0.80	0.90	0.75
		ppm on dry basis		
Fe	40	50	50	---
Zn	25-31	40	40	38(34)
Cu	9-11	10	10	10.5(8.8)
Mn	20-25	40	40	52
Se	0.05-0.10	0.10	0.30	---(0.10)
Mo	------	------	------	0.37
Co	0.11	0.10	0.10	0.22(0.15)

[Z] 600 kg for body weight and 30 kg/d for milk yield.
[Y] Calculated from 24 balance trials at 18℃.
Note : In parenthesis estimates from feeding trials.

Two experiments were conducted to evaluate the effect of hot environmental temperature on the mineral balance in lactating cows : Four lactating cows in each experiment were

Table 4 Body weight, milk yield, and dry matter (DM), water and block salt (BS) intake in lactating cows under high temperature conditions

	Treatment means			Treatment	l. s. d
	18℃	26℃	30℃	effect	(P<.05)
Expt 1 (n=4)					
Body weight, kg	588.5	580.8	548.0	**	20.5
Milk yield, kg/d	26.0	25.2	19.7	**	3.4
DM intake, kg/d	18.2	16.9	12.2	**	2.1
Water intake, kg/d	72.7	75.6	60.6	*	9.8
BS intake, g/d	2.6	1.3	1.9	NS	
Expt 2 (n=4)					
Body weight, kg	561.1	542.5	527.8	**	15.4
Milk yield, kg/d	27.5	23.3	19.3	**	3.9
DM intake, kg/d	18.1	14.8	12.1	**	2.9
Water intake, kg/d	89.1	81.0	71.7	NS	
BS intake, g/d	12.7	16.0	7.0	NS	

Note : ** P<.01, * P<.05, NS Not significant.

Table 5-a Calcium and phosphorus balance (mg/kg body wt per day) in lactating cows under high temperature conditions

	Treatment means			Treatment	l. s. d
	18℃	26℃	30℃	effect	(P<.05)
Ca balance					
Expt 1 (n=4)					
Intake	202.7	199.5	173.5	*	22.6
Secretion in milk	48.0	46.3	37.2	**	5.6
Apparent absorption	33.7	37.9	22.4	*	10.3
Retention	−14.7	−8.8	−15.2	NS	
Expt 2 (n=4)					
Intake	411.8	352.9	293.0	*	86.7
Secretion in milk	64.8	58.2	48.3	*	8.8
Apparent absorption	132.1	119.3	121.1	NS	
Retention	66.0	60.5	72.2	NS	
P balance					
Expt 1 (n=4)					
Intake	125.1	120.8	102.2	*	13.7
Secretion in milk	40.7	38.4	29.0	**	5.7
Apparent absorption	37.2	33.7	17.6	*	12.8
Retention	−4.0	−5.2	−11.5	NS	
Expt 2 (n=4)					
Intake	202.6	176.3	146.4	*	42.8
Secretion in milk	41.4	34.9	27.6	**	6.2
Apparent absorption	44.4	38.4	34.0	NS	
Retention	2.0	2.8	5.6	NS	

Note : ** P<.01, * P<.05, NS Not significant.

Table 5-b Zinc and copper balance (mg/kg body wt per day) in lactating cows under high temperature conditions

	Treatment means			Treatment	l. s. d
	18℃	26℃	30℃	effect	(P<.05)
Zn balance					
Expt 1 (n=4)					
Intake	0.96	0.92	0.74	**	0.11
Secretion in milk	0.18	0.20	0.15	*	0.03
Apparent absorption	0.13	0.09	−0.02	*	0.10
Retention	−0.07	−0.12	−0.18	NS	
Expt 2 (n=4)					
Intake	1.60	1.38	1.17	**	0.29
Secretion in milk	0.20	0.20	0.12	NS	
Apparent absorption	0.23	0.09	0.20	NS	
Retention	−0.01	−0.14	0.04	NS	
Cu balance					
Expt 1 (n=4)					
Intake	0.274	0.270	0.229	*	0.031
Secretion in milk	0.007	0.008	0.004	NS	
Apparent absorption	0.008	0.028	0.005	*	0.013
Retention	0.001	0.018	−0.001	NS	
Expt 2 (n=4)					
Intake	0.366	0.315	0.262	*	0.069
Secretion in milk	0.002	0.002	0.002	NS	
Apparent absorption	0.029	0.027	0.026	NS	
Retention	0.020	0.017	0.027	NS	

Note : ** P<.01, * P<.05, NS Not significant.

exposed to temperatures of 18°, 26° and 30℃, respectively at 60% relative humidity for 2 weeks per treatment. In the feeding trials, the mineral content in milk and serum of 55 lactating cows was determined at high and optimum temperatures under actual conditions.

Body weight, daily milk yield and dry matter intake of the cows in balance trials decreased with temperatures above 26℃, and water and block salt intake tended to decrease above 26℃ (Table 4). In feeding trials, the body weight and daily milk yield of the cows decreased in a hot environment, especially at higher monthly temperatures such as above 26℃ during July to August.

Mineral intake in lactating cows, which was associated with feed or block salt intake, decreased with increasing temperature (ex. Table 5-a and 5-b). Since the ratio of the intake of each mineral including 12 elements in lactating cows at 26℃ to 18℃ ranged from 80 to 99% in Expts 1 and 2, the reduced mineral intake at high temperatures may adversely affect the mineral metabolism in lactating cows. Apparent absorption of each mineral tended to decrease at high temperatures, but higher mineral intake increased the mineral absorption at high temperatures. Also, heat stress in summer reduced the Ca, P, Mg, Na and K concentration in the serum of lactating cows in feeding trials. These results indicated that the mineral metabolism in lactating cows was adversely affected under high temperature conditions.

The assessment of the mineral requirement of lactating cows at a high temperature is necessary to enable them to maintain the same productivity as that at an optimum temperature. Additionally, the use of $NaHCO_3$, $KHCO_3$ and K_2CO_3 is effective for improving the feed intake, milk yield and milk composition in a hot environment due to their roles as buffers and due to the increased requirement of Na and K at a high temperature (Beede and Collier, 1986 ;

Erdman, 1988). This report suggested that the correction of reduced mineral intake under high temperature conditions compared to optimum temperatures is most important for heat-stressed cows and the increase of dietary mineral content is most useful for heat-stressed cows due to the decrease in the feed intake in a hot environment.

In conclusion, the dietary mineral requirements of lactating cows may be higher at a high temperature compared with those under optimum temperature conditions, since the intake and apparent absorption of each mineral in lactating cows were depressed by heat stress. Although the exact value of the mineral requirement of lactating cows under high temperature conditions remains to be determined, the dietary mineral requirement should be increased by about 10 to 20% at high temperatures compared to that at optimum temperatures.

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Discussion

Lopes, H. O. S. (Brazil) : Did you use radio-isotopes in your studies to determine the true absorption of phosphorus. Indeed there are problems with apparent phosphorus absorption in relation to endogenous phosphorus.

Answer : We did not use radio-isotopes in our studies due to the strict regulations on the use of radio-isotopes in Japan.