The Seasonal Change in Energy Conversion from Feed to Milk Yield and Body Retention of Holstein Dairy Cows

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Experimental Farm

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SUMMARY

In order to describe the energy flow from feed allowance to milk and body and its seasonal change under actual condition of raising dairy cows, the relations among the factors in the energy flow and environmental temperature were analyzed.

The data of feed allowances, milk yields, milk fat rates and body weights of dairy cows under farmers' identical management during nine years were used for mathematical modeling based on a scientific knowledge of animal nutrition. The values of metabolizable energy allowances, milk yields, body accumulations, heat productions (each MJ/mbs/day), gross energetic efficiencies (GEE), and utilized efficiency for milk (kl) were calculated. Regression analyses among those calculated values clarified the influence of air temperature on them. The results are as follows. (1) Seasonal changes were seen in all the data for energy balance, and GEE for milk was high in April, May, September and October. (2) Seasonal changes in GEE for milk and body retention from diet were in the range of 28~34% and 1~9%, those were 31% and 4% on the year averages, respectively. (3) The calculated utilized efficiency was kl=58.57%. (4) Metabolic energy allowance showed positive correlations to milk energy and heat production, but not to body retention nor to all GEE. (5) The environmental temperature showed the relations of a negative parabola to GEE for milk and body retention.

For the improvement of milk production, the above results had the following importance, which was to increase metabolizable energy allowance during the time when high efficiency to milk yields is shown, and which was to act as a control for preventing a decline in milk efficiency during hot weather. Res. Bull. Fac. Agr. Gifu Univ. (60) : 181—189, 1995.

INTRODUCTION

Energy flow and its seasonal change in an actual dairy cow herd should give useful information on breeding conditions and improving management through the year.

Energy balance of dairy cows depends on the energy intake, the energy conversion rate to milk and body, and the energy conversion rate from body tissue to milk. As these components are influenced by various feeding environmental factors, the understanding of the energy balance of a dairy cow herd under a general feeding system is usually very difficult. Some research has been done on the relations between environmental factors and the energy balance of dairy cows[1-4)], but their measuring periods are rather short. We tried to understand the seasonal variation in energy balance under an actual feeding system, and to earn its relevance to feed allowance and air temperature. We intended at next step to apply these results to the improvement of feeding management.

1) *Institute for Basin Ecosystem Studies*

In this research, the authors analyzed the feeding data of a dairy cow herd during nine years by applying a scientific knowledge of animal nutrition, and calculated the values of feed energy allowances, milk yields, body accumulations and heat productions. Then we showed those seasonal changes, and analyzed the influence of temperature on them.

MATERIALS AND METHODS

1. Data used

The authors used the monthly values of milk yield, milk fat percentage, body weight and allowance of concentrate for the lactating Holstein cows raised in our Animal Husbandry Experiment Station (The University of Tokyo) as measurement data over nine years from 1980 to 1988 (each n=1260). The monthly amount of roughage given the herd during this period was also used (each n=108).

All energy measurements in this paper were shown with the values per metabolic body size (mbs). This was calculated by raising each weight measurement value of individuals to the 0.75th power.

2. Seasonal feed energy allowance (MEa: MJ/mbs/day)

Feed energy allowances were expressed by the metabolic energy quantities in the feeds given to the herd each month. The quantities were calculated by multiplying the feed allowance by its metabolic energy content (in Japanese Feeding Standard, Feed Component, 1987), and were expressed as the values per metabolic body size per day.

The metabolizable energy in the roughage intake was calculated by using the values of various roughage quantities given to the cows, the metabolic body size of the cow herd in total measured monthly, and the number of days in each month. The metabolizable energy of the concentrate intake was calculated for each individual apart from the calculation of the roughage, and they both were averaged in each month.

Seasonal feed energy allowance (MEa: MJ/mbs/day) was calculated as the sum of the metabolic energy allowances of the concentrate and the roughage in each month.

3. Seasonal body retention energy from diet (REdiet: MJ/mbs/day)

The monthly body retention energy (REindiv: MJ/mbs/day) of individual can be shown by multiplying their daily gain (DGindiv: kg/mbs/day) by an energy value for the gain (MJ/kg).

$$\mathrm{REindiv} = \mathrm{DGindiv} \cdot 26 \ / \ \mathrm{mbs}, \qquad (1)$$

where DGindiv is calculated from weight data of each month per individual, and the numerical value in the formula shows the recommended energy value (MJ/kg) in ARC[5], when a cow's body weight varies by one kilogram.

The feed allowance is never lower than the maintenance requirement in the actual feeding spot. The authors, therefore, supposed that the observed decreases in weight originate in the change of energy from body tissues to milk production, and that all increases of weight in the data are dietetic in origin. If this supposition is followed, the bodily accumulated energy from diet (REindiv-diet: MJ/mbs/day) of each individual becomes the following equation.

$$\text{If } \mathrm{REindiv} > 0, \ \mathrm{REindiv\text{-}diet} = \mathrm{REindiv},$$
$$\text{if } \mathrm{REindiv} \leqq 0, \ \mathrm{REindiv\text{-}diet} = 0. \qquad (2)$$

The seasonal body retention energy from diet (REdiet: MJ/mbs/day) was calculated by averaging the REindiv-diet of the cows in each month.

4. Seasonal production of milk energy from diet (Ydiet: MJ/mbs/day)

Milk energy yields of each month per individual (Yindiv: MJ/mbs/day) was presumed by using data for the milk fat rate (F: %) measured once a month together with the milk yields (M: kg/day).

$$\text{Yindiv}=\text{M}\cdot(0.15\cdot\text{F}+0.4)\cdot 3.138\ /\ \text{mbs}. \qquad (3)$$

This formula makes 3.138 megajoules (=0.75Mcal) of the energy value per one kilogram of 4 percent fat-corrected milk. From the above supposition, each individual's milk energy from diet (Yindiv-diet: MJ/mbs/day) with an increase in body weight is equal to the value of Yindiv, and that with a weight decrease must subtract the milk energy of body tissue origin from the value of Yindiv. Moe et al.[6], who showed utilized efficiencies from body tissue to milk energy in the range from 0.82 to 0.84, ARC[5] also recommend the value of 0.84. The authors adopted the value of 0.84, and deduced Yindiv-diet from the following equation.

$$\text{If REindiv}\geqq 0,\ \text{Yindiv-diet}=\text{Yindiv},$$
$$\text{if REindiv}<0,\ \text{Yindiv-diet}=\text{Yindiv}-0.84\cdot\text{REindiv}. \qquad (4)$$

The seasonal milk energy from diet (Ydiet: MJ/mbs/day) was calculated by averaging the Yindiv-diet of the cow herd in each month.

Then, the authors defined that the values arrived at by subtracting REdiet and Ydiet from MEa in each month were heat productions from diet of each month (HPdiet: MJ/mbs/day).

$$\text{HPdiet}=\text{MEa}-\text{REdiet}-\text{Ydiet} \qquad (5)$$

5. Gross energy efficiency (GEE: %) of feed metabolic energy in each season

The conversion rates (GEE: %) from feed metabolic energies to milk yields, body accumulations and heat productions were shown as the following formula by using the above values.

On feed origin,

$$\text{GEE for milk}=\text{Ydiet}\ /\ \text{MEa}\cdot 100$$
$$\text{GEE for retention}=\text{REdiet}\ /\ \text{MEa}\cdot 100$$
$$\text{GEE for heat production}=\text{HPdiet}\ /\ \text{MEa}\cdot 100 \qquad (6)$$

6. Analytic technique

Technique 1: By averaging the values of the metabolic energy allowances, milk yields, body accumulations, heat productions, and their gross energy efficiencies, respectively, the authors got their representative values. Their seasonal changes were shown by classifying those values in each month. Then the authors tried to calculate the utilized efficiency of a feed metabolic energy for milk (kl) by supposing a value of 0.5265 as the maintenance requirement (MEm: MJ/mbs/day)[7,8].

Technique 2: The energy balance of dairy cows can be separated by the metabolic energy allowance, the productive energy and the distributive rates from the allowance to the productions. To know the relations among these factors, the authors carried out the regression analysis, in which the independent variable is the metabolic energy allowance.

Technique 3: As mentioned below, these results showed that the energy balance of the herd shows seasonal changes, and that the changes are influenced by both the metabolic energy allowance and the individual gross energetic efficiencies. The authors, therefore, examined the influence of environmental temperature on those efficiencies by regression analyses; the temperature is one factor in the seasonal changes.

RESULTS

The energy flows from metabolic energy allowances to milk yields, body accumulations and heat production and those gross energetic efficiencies are revealed in the following figures: Fig.1 shows the total average of all data; Fig.2 shows those seasonal changes. The levels of metabolic energy allowances (MEa: MJ/mbs/day) changed in a range from 1.26 to 1.41 (average 1.34), being lower from March to May (1.26~1.28), and higher from August to November (1.37~1.41). They then

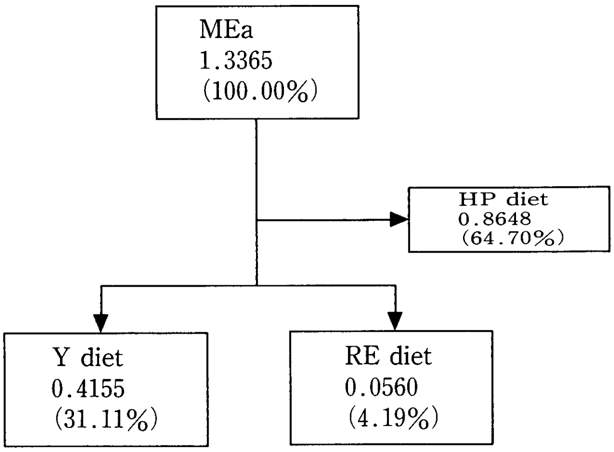

Fig.1. Representative values (MJ/mbs/day) of energy flows from the metabolic enegy allowance to milk yield, body retention and heat production. The values in parentheses are the converted rate (%) of energy from the metabolic energy allowance to each item.

decreased in December and January. The milk energy from diet (Ydiet: MJ/mbs/day) changed in a range from 0.38 to 0.45 (average 0.42), increased from September through November (0.44～0.45), and showed declines in December, January and March (0.37～0.38). The body retention energy from diet (REdiet: MJ/mbs/day) varied in a range from 0.01 to 0.11 (average 0.06), rose in May, June and September (0.10～0.11), and decreased from December to January and in again March (0.01～0.03). The heat production from diet (HPdiet: MJ/mbs/day) markedly rose to 0.95 from 0.73 (average 0.86), rose in June, August and from November to February (0.90～0.95), and decreased from April to June and in again September (0.73～0.81).

The gross energetic efficiencies (GEE) for milk, for body retention and for heat production were in the range of 28～34%, 1～9% and 57～71%, respectively, and those were 31%, 4% and 65% on the averages, respectively. The changes in energy corresponded with those in each gross efficiency. In April and May, however changes in efficiency for milk were high (32% and 34%, respectively), in comparison with changes in the energy for milk.

The same seasonal change emerged between the metabolic energy allowance and the milk energy of feed origin from September to March. The heat production increased from July to November except in September, and decreased from March until June. Those changes corresponded with changes in energy allowances during those periods.

The utilized efficiency of the feed metabolic energy for milk (kl) can be presumed from the study of Coppock et al.[1] and Flatt[9] by the following formula.

$$kl = Ydiet \;/\; (MEa - MEm - MEg), \qquad (7)$$

where Ydiet is the milk energy from diet, MEm is a metabolic energy requirement for maintenance and MEg is its requirement for body retention.

Since ARC[5] makes [0.95 · kl] of the utilized efficiency of the feed metabolic energy for a cow's body retention (kf), MEg can be shown by the following formula.

$$MEg = REdiet \;/\; kf = REdiet \;/\; (0.95 \cdot kl), \qquad (8)$$

where REdiet is body retention energy from diet. By substituting formula (8) into formula (7), the authors expressed the utilized efficiency of the feed metabolic energy for milk (kl) by the following formula.

$$kl = (0.95 \cdot Ydiet + REdiet) \;/\; \{0.95\,(MEa - MEm)\} \qquad (9)$$

The authors substituted the representative values (Fig.1) derived from the above analysis into MEa, Ydiet, REdiet in formula (9), and then supposed the value of 0.5265 as MEm (MJ/mbs/day) of the dairy cow[7,8]. As a result, the utilized efficiency for milk (kl) was shown as the following numerical value.

$$kl = 0.5857$$

Table 1 indicates the regression formulas between the metabolic energy allowance, which is an independent variable, and the energy of milk, body retention and heat production. The formulas,

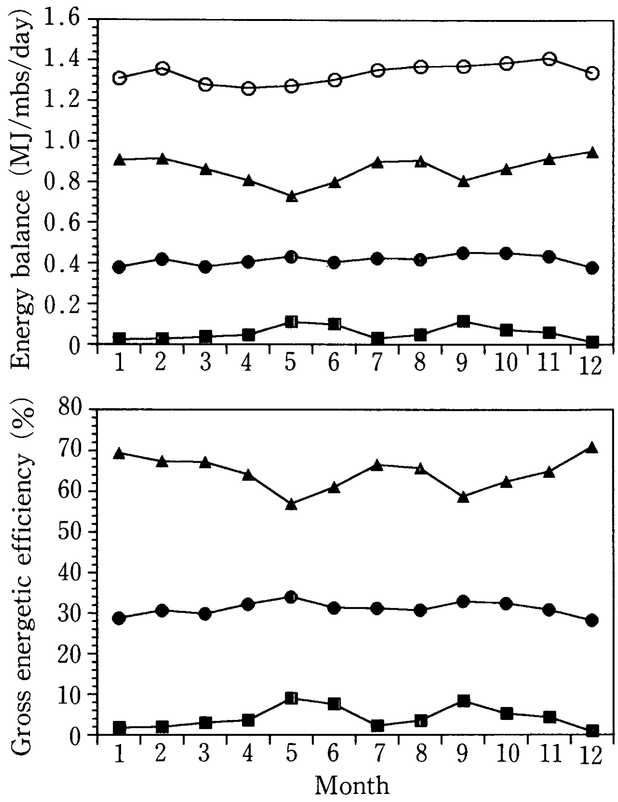

Fig.2. The seasonal change in energy balance and the gross energetic efficiency in a dairy cow herd. The top line graph shows metabolic energy allowance, milk yield, body retention and heat production from diet. The bottom one is gross energetic efficiency to these energy factors.

being correlations, showed the relations of positive straight lines. The metabolic energy allowance was involved moderately in the changes in milk energy ($r=0.48$, $p<0.001$) and heat production ($r=0.63$, $p<0.001$), but no significant involvement was found with the change in body retention energy ($r=0.09$, $p>0.05$). Moreover, no gross efficiency was found to depend on the metabolic energy allowance ($r=0.02\sim0.17$, each $p>0.05$).

The authors presented the relations between air temperature, which was an independent variable, and metabolic energy allowance or individual gross energetic efficiency in Table 2 and in Fig.3. The result was that no relation was shown between air temperature and metabolic energy allowance. The efficiencies for milk, body retention and heat production were described in the parabola to the environmental temperature as seen in Fig.3. The authors, therefore, arrived at the formulas in Table 2 by applying these data to quadratic equations. Those equations showed some reliable correlations ($r=0.26$, 0.38 and 0.37; $p<0.05$, <0.001 and <0.001, respectively). The efficiencies for milk and body retention increased with air temperature from the low temperature to 15～20℃, and decreased under the temperature above it. Those for heat production showed a trend opposite to those for milk and body retention.

DISCUSSION

For increasing milk yields in December, January, April and May when the low yields were shown, the metabolizable energy intake and its efficiency must be improved by some methods, such as a diet allowance of a high metabolic rate and high palatability. The decreases in milk energy yields from diet in January and December are due to the declines in the metabolic energy allowance and its efficiency for milk. The milk energy (MJ/mbs/day) in April and May was 0.40 and 0.43, respectively. Those values are close to the total average (0.42), but the gross energetic efficiencies were 32.2% and 34.0%, respectively, which were higher than the total average of 31%. The metabolic energy allowances (MJ/mbs/day) in the terms were 1.26 and 1.27, which were lower than the total average of 1.34. Moran[4] showed that the metabolic energy intakes of dairy cows in winter and spring were the highest of the year. He also showed that FCM yields per metabolic energy (energetic efficiency) were high in spring (0.139) and low in winter (0.121). Brody[10] pays attention to the rise in milk production in May. Shibata and Mukai[11] showed that cow's TDN intakes in November, January and March were high (more than 11 kg) for the year. They also observed that the intakes

Table 1. Correlation between energy balance and metabolic energy allowance

	No. of data	Formula	r=	
Milk yield				
observed (MJ/mbs/day)	107	0.3206・MEa+0.0092	0.5560	***
from MEa (MJ/mbs/day)	107	0.3151・MEa−0.0052	0.4804	***
GEE (%)	107	0.9553・MEa+29.832	0.0217	NS
Body retention				
observed (MJ/mbs/day)	107	−0.0530・MEa+0.1010	0.0733	NS
from MEa (MJ/mbs/day)	107	−0.0460・MEa+0.1181	0.0937	NS
GEE (%)	107	−6.5595・MEa+13.073	0.1715	NS
Heart production				
from MEa (MJ/mbs/day)	107	0.7312・MEa−0.1130	0.6305	***
GEE (%)	107	5.6043・MEa+55.095	0.0806	NS

MEa: Metabolic enegy allowance (MJ/bs/day), GEE: Gross energetic efficiency (%), r: Correlation coefficient. 'Observed' is the actual produced energy. 'From MEa' is the energy coming from metabolic energy in the diet. Level of significance: ***P<0.001; NS: Not significant

Table 2. Correlation between environmental temperature and metabolic energy allowance or gross energetic efficiencies.

	No. of data	Formula	r=
MEa (MJ/mbs/day)	107	$-0.0012 \cdot \mathrm{Temp}+1.3188$	0.0752 NS
GEE (%) for			
milk yield	107	$-0.0234 \cdot \mathrm{Temp}^2+0.7295 \cdot \mathrm{Temp}+27.1555$	0.2570*
body retention	107	$-0.0254 \cdot \mathrm{Temp}^2+0.8498 \cdot \mathrm{Temp}-0.7654$	0.3792***
heat production	107	$0.0488 \cdot \mathrm{Temp}^2-1.5793 \cdot \mathrm{Temp}+73.6098$	0.3691***

MEa: Metabolic enegy allowance (MJ/mbs/day), GEE: Gross energetic efficiency (%),
Temp: Air-temperature (℃), r: Correlation coefficient, Level of significance: ***P<0.001; *P<0.05;
NS: Not significant.

in June and August were a low 9.50 kg and 9.58 kg, respectively. These reports suggest that the above mentioned improvement is effective.

As for the values of the gross energetic efficiency for milk, Naitoh et al.[12] showed a value of 25.9%; Hashizume[13] arrived at values from 28.3 to 32.3%. The authors have also gotten trial values of 30.5~34.1% and 32.2%, respectively, by using data of Coppock et al.[1] and Flatt[9]. The value of 31.1% in this paper approximates all the above values except that of Naitoh et al.[12].

At present, regression analysis is generally used for estimating of the utilized efficiency for milk (kl), in which the dependent variables are for milk energy and the independent ones are for metabolic energy allowance. Since the energy data in this research was not derived from an experimental program, the dispersion of data was great; the range of variation in metabolic energy allowances was small. Regression analysis, therefore, could not be used. Thus the authors obtained the value of kl= 58.6% by supposing that the value of the maintenance requirement (MEm: MJ/mbs/day) in the formula (8) was 0.5265, and that the compensation at increasing weight was obtained as in formula (3). Coppock et al.[1] calculated the value of kl=54~65% by the same method, where MEm was supposed as 0.55 and the compensation value to the gain of body weight was 1.61. However, the values derived by using this method will change with changes in the establishment values of the cow's maintenance requirement, as can be seen in the study of Flatt[9]. The maintenance requirement used

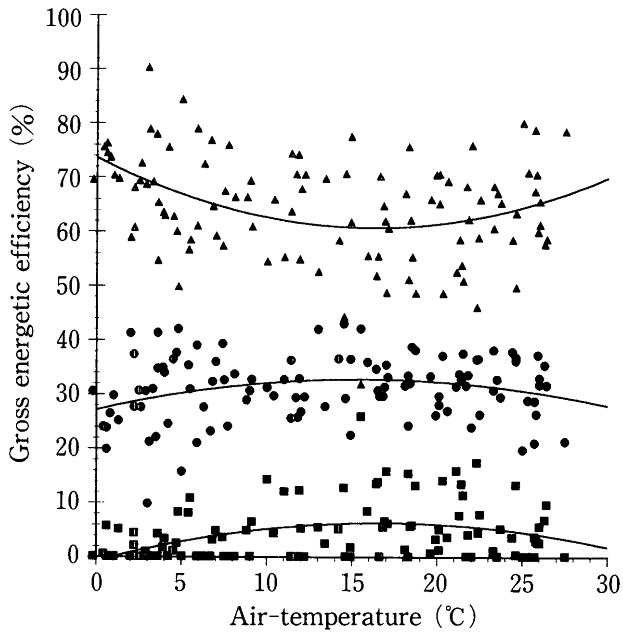

Fig.3. The relationship between enbironmental temperature and gross energetic efficiencies. The gross energetic efficiency is the comverted rate (%) from metabolic energy allowance to milk yield, body retention and heat production. These efficiencies describe parabolas to the air-temparature.
• Milk yield ▪ Body retention ▴ Heat production

in our research (0.5265 MJ/mbs/day) is calculated by multiplying the supposed fasting metabolism (0.39 MJ/mbs/day) by the value of 1.35. This method accords with the thought of Blaxter concerning the relations between fasting metabolism and maintenance requirement[7]. Hashizume[8] referred to the difficulty in measuring directly the maintenance requirement of dairy cows, and then showed the values of 0.36, 0.39 and 0.40 as the fasting metabolism. By using regression analysis, Moe et al.[14] showed the values of kl=54~65%, and Sekine et al.[2] expressed the value of kl=59% as the utilized efficiency for milk. These values approximate the value of 58.6% in this paper.

The relations between air temperature and metabolic energy allowance could not be shown in this paper (Table 2). One explanation for this may be that the metabolic energy allowances in winter and spring were smaller than the possible intakes of the observed dairy cows. This is because a dairy cow's intake generally decreases in summer, and we did not calculate such countermeasures to heat as air conditioning, sprinkled water or feed of high quality.

Air temperature has some influence on gross energetic efficiency. At high temperatures, the efficiency for heat production rose, and those for milk and body retention decreased. Shibata et al. showed that the heat production of dry[15] and dairy cows[3,16] rose under high temperatures. Furthermore, the same holds true of decreasing gross efficiency for milk at high temperatures. These reports correspond with the trends for gross energetic efficiencies for milk yield and heat production in summer in this paper. Our results confirmed their suggestion[16] that the rate of metabolic energy converted to body system, not to milk, at high temperature increased more than that at the suitable temperature.

In cold temperatures, the gross energetic efficiency for milk and body retention decreased. Shijimaya et al.[17,18] carried out two examinations of dairy cows exposed to cold conditions, and they got two different results as follows. One decreased the efficiency of milk production under cold conditions, and the other raised it. Thus, clarification of this point awaits further study.

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ホルスタイン種乳牛群における飼料から乳及び体蓄積へのエネルギー流とその季節変動

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附属農場

1)流域環境研究センター

要　　約

本研究では，実際に飼養されている泌乳牛群の給与飼料から乳及び体蓄積までのエネルギーの流れとその季節変動値を示し，それらの相互の相関および環境温度との関係を解析した。実際の飼養管理下にある泌乳牛の９年間の飼料給与量，乳量，乳脂率，体重のデータを栄養学の知見を基にした数学的手法で処理することにより，代謝エネルギー給与量，飼料由来の泌乳，体蓄積，熱発生のエネルギー(MJ/mbs/day)とそれらのための総効率（GEE）および泌乳のための代謝エネルギーの利用効率（kl）を算出した。これら求められた値間とそれらと月平均気温の関係を回帰分析により解析し，次のような結果を得た。

(1)エネルギー収支のデータにはすべて季節変動がみられ，泌乳のための総効率は４，５月と９，10月に高い。 (2)飼料由来の泌乳，体蓄積のための総効率の季節変動は各々GEE＝28～34，１～９％の範囲にありその平均は31.４％であった。 (3)算出された代謝エネルギーの利用効率はkl＝58.57％を示した。 (4)代謝エネルギー給与量は飼料由来の泌乳，熱発生量と正の相関を示したが，体蓄積エネルギーおよび全ての総効率とは相関を示さなかった。 (5)環境温度は，飼料由来の泌乳と体蓄積のための総効率との間に，負の放物線上の関係を示した。

以上の結果から，エネルギー収支とその効率には季節変動が存在し，乳生産向上のためには，泌乳への高い効率を示す時期の代謝エネルギー給与量の増加や，高温時期の泌乳効率の低下防止に対する防暑管理の重要性が示唆された。

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