The Changes in Energy Flow from Feed to Production during Lactation in Holstein Dairy Cows, and How They are Influenced by Calving Numbers

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The Changes in Energy Flow from Feed to Production during Lactation in Holstein Dairy Cows, and How They are Influenced by Calving Numbers

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SUMMARY

The energy balance in lactating cows was analyzed for changes during lactation and to determine the influence of calving numbers on such changes. Data used are the values of feed allowances, milk yields, milk fat percentages and the body weights of a cow herd raised between 1980 and 1988, together with the monthly average of air temperatures during that period. The animals' individual values of metabolizable energy allowances, milk yields, body retention and heat production (each mj/mbs/day) on the feed origin and the gross energetic efficiency (%) were calculated by using mathematical techniques based on dietetics. The changes during lactation of the above values are as follows. 1. Metabolizable energy allowances, milk yields and heat production increased with increasing calving numbers. 2. Body retention and its gross energetic efficiency decreased with increasing calving numbers. 3. No differences among calving numbers were seen in gross energetic efficiencies for milk and heat production. 4. Decreases after the first or second month of lactation were seen in metabolizable energy allowance, milk yields, heat production and gross energetic efficiency for milk. 5. Body retention rose at the fifth or sixth month in the period, and was steady after that. 6. The rises in gross energetic efficiencies were reflected in body retention after the fifth or sixth month of lactation, and in heat production after the first or second months. 7. The gross energetic efficiency for milk was strongly affected by lactating times in contrast to gross energetic efficiencies for body retention or heat production. These results lead to the conclusion that the peculiar changes in energy balance during lactation are due to the changes in metabolizable energy intake and all gross energetic efficiencies.

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INTRODUCTION

The purpose of this paper is to clarify the influence of the lactating period and calving numbers on the energy flow in an actual cow herd. Some researchers[1, 2, 3, 4] report that there is a seasonal change in a cows' energy flow. We also showed previously that the seasonal change occurred due to changes in both diet energy allowances and the rate of conversion from the allowance to production: gross energetic efficiency[2]. It seems, however, that the variations in the energy balance of dairy cows was more affected by factors such as lactating time and calving numbers. Accordingly, the influence of these factors must also be examined for the appropriate management of dairy cows.

In this research, mathematical formulae were applied to measurement data of an actual cow herd over nine years. These formulae were developed based on the findings of nutritional science. We compared the changes in calculated values during lactation and for each calving number, together with feed allowances, milk yields, body retention, heat production and gross energetic efficiency. The correlations among gross energetic efficiencies, calving numbers, lactating time and environmental temperature were then shown by

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multiple regression analysis.

MATERIALS AND METHODS

Data used

For analysis, 127 examples of cows' lactation data were collected from a Holstein herd raised in the Animal Husbandry Experimental Station of The University of Tokyo, covering the years from 1980 to 1988. These examples consist of data on milk yields, milk fat percentages and body weights during lactation. These were classified into the following four calving numbers: first calving 41, second 29, third and fourth 35, and fifth or higher 22. The one example consists of monthly measurement values during a ten-month in a dairy cow. Added to these, we used data on monthly roughage given to that dairy cow's group (n=108), and on the concentrate given to each individual cow (n=1260).

All energy values in this paper were shown per metabolic body size (mbs), which was calculated by raising each individual body weight to the 0.75th power.

Metabolizable energy allowance (MEa: mj/mbs/day) during lactation

The individual *MEa* during lactation was shown as the sums of concentrate and roughage given to each individual; details are in the thesis of Itano and Okubo[2]. Those values could be further classified by each postpartum month.

Body retention from diet (REdiet: mj/mbs/day) during lactation

Body retention energy (*RE*, mj/mbs/day) was shown by multiplying each individual daily gain (*DG*: kg/day) during lactation by the numerical value of 26, as in the following formula.

$$RE = DG \cdot 26 / mbs \qquad (1)$$

Where *DG* was derived from the data of individual body weights during lactation, and the value of 26 is an energy value (mj/kg) recommended by the Agricultural Research Council (1980: ARC) required to produce a one-kilogram weight change in a lactating cow[5].

The energy level given to a lactating cow will always exceed the maintenance requirement. For this reason, we assumed as follows; decreases in weight occur due to energy modification from body tissue to milk; increases in weight are dietetic in origin. If these hypotheses are followed, the body retention energy from diet (*REdiet*, mj/mbs/day) during lactation can be shown as follows.

$$\text{If } RE \geqq 0, \quad REdiet = RE$$
$$\text{if } RE < 0, \quad REdiet = 0 \qquad (2)$$

Milk yields from diet (Ydiet: mj/mbs/day) during lactation

Each milk energy value (*Y*: mj/mbs/day) was calculated by using the data of both measured milk fat percentages (*F*: %) and milk yields (*M*, kg) at each measured time, as in the following formula.

$$Y = M \cdot (0.15 \cdot F + 0.4) \cdot 3.138 / mbs \qquad (3)$$

From the hypotheses mentioned above, the milk yields with decreases in body weight must be modified by decreases coming from body tissue.

$$\text{If } RE \geqq 0, \quad Ydiet = Y$$
$$\text{if } RE < 0, \quad Ydiet = Y - 0.84 \cdot RE \qquad (4)$$

Where, $[0.84 \cdot RE]$ shows the energy flow from body tissue to milk yields (ARC[5] and Moe et al.[6]).

Heat production (*HPdiet*; mj/mbs/day) was then defined as the value left after subtracting the energies of both milk and body retention from the metabolizable energy allowance.

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

Gross energetic efficiency (%) during lactation

The converted rates of energy (*GEE*; %) from feed to milk, body retention and heat production, respectively, were reached by using the calculated values above as follows.

On feed origin,

GEE for milk = *Ydiet / MEa · 100*

GEE for retention = *REdiet / MEa · 100*

GEE for heat production = *HPdiet / MEa · 100* (6)

Analysis

Analysis 1: We classified the calculated values (*MEa, Ydiet, REdiet, HPdiet* and their gross energetic efficiencies) into the first, second, third and fourth, and fifth or higher calving, respectively; then the changes in those values during lactation were compared among calving numbers. For comparison analysis, the Friedman test was adopted.

Analysis 2: In order to examine the influence of lactating time, calving numbers and environmental temperature upon the above gross energetic efficiencies, we performed a multiple regression analysis in which the dependent variable is the gross energetic efficiency.

RESULTS

Table 1 summarizes the mean values of the metabolizable energy allowance, milk yields, body retention, heat production and their gross energetic efficiency in each calving number. The changes in those values during lactation are shown in Fig. 1 and Fig. 2.

Table 1. The average values of metabolic energy allowance, milk yields, body retention, heat production, and these gross energetic efficiencies on each calving number during lactation.

	Calving number				
	First n=41	Second n=29	Third - fourth n=35	Fifth or more n=22	
ME allowance (MJ/mbs/day)	1.2789	1.3418	1.4153	1.3935	***
From diets					
Milk yield (MJ/mbs/day)	0.4127	0.4549	0.4762	0.4619	**
Body retention (MJ/mbs/day)	0.0848	0.0708	0.0713	0.0614	
Heat production (MJ/mbs/day)	0.7814	0.8161	0.8678	0.8702	*
Gross energetic efficiency for					
Milk yield (%)	31.8239	33.3191	33.1504	32.6644	
Body retention (%)	6.9681	5.6158	5.4063	4.7953	
Heat production (%)	61.208	61.065	61.4433	62.5403	

Level of significance: ***P < 0.001; **P < 0.01; *P < 0.05

The metabolizable energy allowance (*MEa*: mj/mbs/day) was different among calving numbers (P<0.001). The mean values of *MEa* through lactation in the third-forth calving (1.42) and the fifth or later one (1.39) were higher than those in the first (1.28) and second calving (1.34); the mean value of *MEa* in the second calving was higher than that in the first calving, but no differences among calving numbers beyond the third one were detected. Metabolizable energy allowances in all the calvings decreased after the second month of lactation. *MEa* of the first and second months rose with calving numbers, provided that *MEa* beyond the third calving held steady (the first calving: 1.53-1.54, the second: 1.58-1.66, the third-forth: 1.74 and the fifth or later: 1.67-1.73). No differences in *MEa* among calving numbers were shown in the 10th month of lactation, when *MEa* were in the range of 1.06 to 1.09.

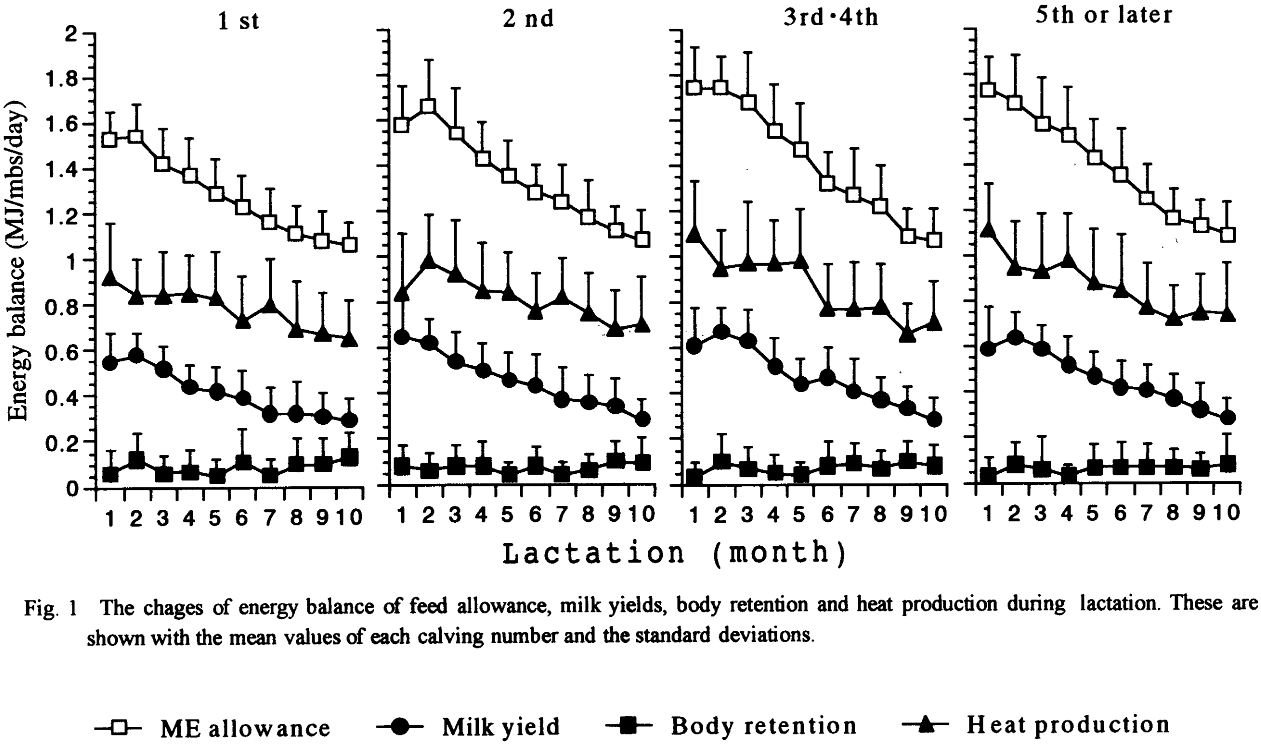

Fig. 1 The chages of energy balance of feed allowance, milk yields, body retention and heat production during lactation. These are shown with the mean values of each calving number and the standard deviations.

Milk yields from diet (*Ydiet*: mj/mbs/day) also showed significant differences among calving numbers ($P<0.01$); *Ydiet* in the first calving were significantly smaller than other calving numbers, but differences in *Ydiet* beyond the second calving were minor: the mean value of *Ydiet* in the first calving was 0.41, whereas values beyond the second were in the range of 0.45 to 0.48. Milk energies which peaked in the first or second month of lactation, showed a value of 0.58 in the first calving, and were in the range of 0.64 to 0.68 in other calving numbers. However, the differences in *Ydiet* at the 10th month of lactation were minor, being in the range of 0.28 to 0.29.

Except for the second calving, the variations in body retention from diet (*REdiet*: mj/mbs/day) during lactation showed the following tendency. The lowest values of *REdiet* were seen in the first, fourth and fifth months of lactation (0.03 - 0.06); *REdiet* was steady after rising in the fifth and sixth months. No significant differences were detected among calving numbers ($P>0.05$), but the mean values of *REdiet* tended to decrease with increasing calving numbers (the first calving: 0.08, the second - fourth: 0.07 and the fifth or later: 0.06).

Heat production from diet (*HPdiet*: mj/mbs/day) decreased in all the calving numbers throughout lactation. These decreases were more gradual than those of the metabolizable energy allowance. The mean values of *HPdiet* then rose with the calving numbers (first calving: 0.78, second: 0.82, beyond third: 0.87; $P>0.05$), and this tendency was the same throughout lactation.

The gross energetic efficiency (*GEE*: %) for milk from diet decreased with lactating time, as did the milk yields. *GEE* in the first calving (the average: 31.8) was only slightly less than in other calving numbers (the averages: 32.7 ~ 33.3), and was not significant ($P<0.05$).

HP: heat production (kj/mbs/min), HR: heart rate (beats/min),**:$P<0.01$
ns: not significant

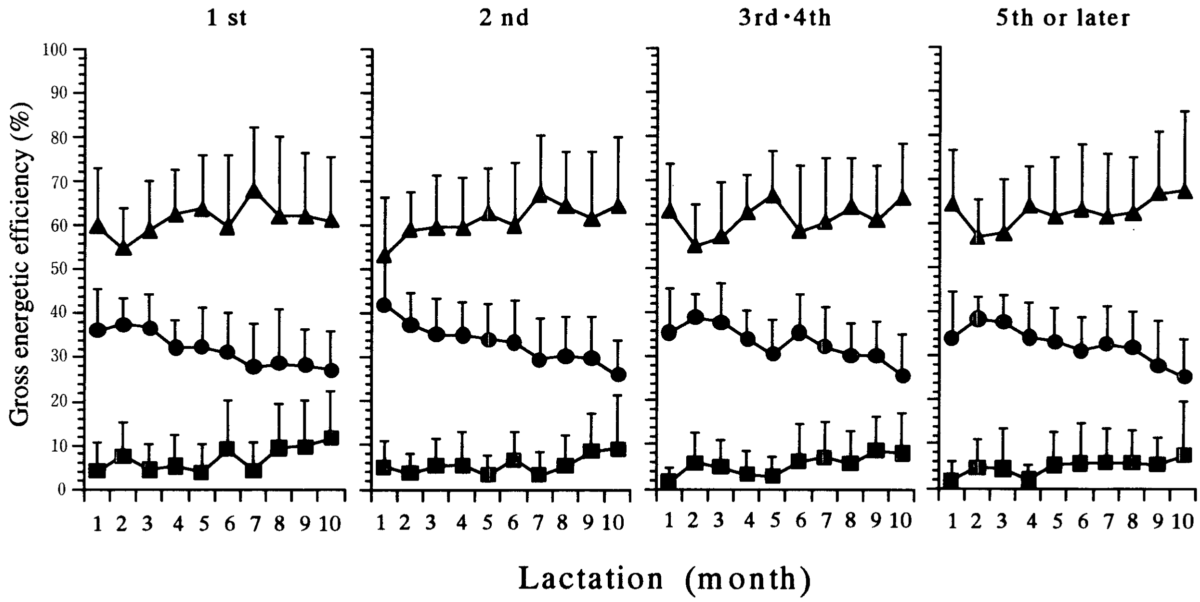

Fig. 2 The changes of gross energetic efficiency for milk yields, body retention and heat production in lactation. They were shown with monthly averages of each calving number and with their standard deviations.

GEE for body retention in the first - fourth calving had been rising since the latter half of the lactating periods (the fourth - seventh month), as long as *GEE* beyond the fifth calving had been holding steady during the period. These increases were more pronounced among the lower calving numbers. For example, *GEE*s at the 10th month showed the values of 11.7 in the first calving, 9.3 in the second, 8.7 in the third-fourth, 7.5 in the fifth or later. The mean values of *GEE* in each calving also decreased with rising calving numbers (the first calving: 7.0, the second: 5.6, the third-fourth: 5.4, the fifth or later: 4.8), but no significant difference was detected (P>0.05).

Table 2. Estimated formulas of the gross energetic efficiencies (%) for milk yields, body accumulations and heat productions, by using lactating time and air temperature.

	n=	Formula	r =	
For milk yield				
First	391	$-1.2020 \cdot Lact - 0.0096 \cdot Temp^2 + 0.4218 \cdot Temp + 35.1699$	0.4160	***
Second	288	$-1.1032 \cdot Lact - 0.0040 \cdot Temp^2 + 0.3586 \cdot Temp + 35.8165$	0.4334	***
Third - fourth	334	$-1.1245 \cdot Lact - 0.0002 \cdot Temp^2 + 0.1387 \cdot Temp + 37.6671$	0.3921	***
Fifth or more	223	$-1.3574 \cdot Lact - 0.0109 \cdot Temp^2 + 0.5425 \cdot Temp + 35.4642$	0.4552	***
Total	393	$-1.3782 \cdot Lact - 0.0148 \cdot Temp^2 + 0.5675 \cdot Temp + 36.3198$	0.4286	***
For body retention				
First	391	$0.5600 \cdot Lact - 0.0307 \cdot Temp^2 + 1.0150 \cdot Temp - 2.3197$	0.3211	***
Second	288	$0.6105 \cdot Lact - 0.0219 \cdot Temp^2 + 0.8437 \cdot Temp - 3.4895$	0.3775	***
Third - fourth	334	$0.4930 \cdot Lact - 0.0184 \cdot Temp^2 + 0.6060 \cdot Temp - 0.8883$	0.2908	***
Fifth or more	223	$0.3155 \cdot Lact - 0.0267 \cdot Temp^2 + 0.8973 \cdot Temp - 2.5344$	0.2962	***
Total	393	$0.4522 \cdot Lact - 0.0286 \cdot Temp^2 + 0.9457 \cdot Temp - 2.6091$	0.3125	***
For heat production				
First	391	$0.6419 \cdot Lact + 0.0402 \cdot Temp^2 - 1.4368 \cdot Temp + 67.1498$	0.2935	***
Second	288	$0.4927 \cdot Lact + 0.0259 \cdot Temp^2 - 1.2023 \cdot Temp + 67.6730$	0.3737	***
Third - fourth	334	$0.6317 \cdot Lact + 0.0186 \cdot Temp^2 - 0.7447 \cdot Temp + 63.2212$	0.2321	***
Fifth or more	223	$1.0419 \cdot Lact + 0.0376 \cdot Temp^2 - 1.4398 \cdot Temp + 67.0701$	0.3421	***
Total	393	$0.9260 \cdot Lact + 0.0433 \cdot Temp^2 - 1.5132 \cdot Temp + 66.2893$	0.3242	***

Lact: lactating time (month), Temp: air temperature (℃), r: correlation coefficient,
Level of significance: ***P<0.001

GEE for heat production rose with lactating times, although the changes in heat production decreased. No differences among calving numbers were seen in *GEE* for heat production; the mean values of each calving were in the range of 61.6 to 62.5%.

The above results showed that *GEE* for milk decreased with lactating time, and that *GEEs* for both body retention and heat production increased with the time. We previously showed that those gross energetic efficiencies may be depicted as parabolas to air temperature[2]. In order to investigate the relation between *GEE* and lactation, therefore, we carried out multiple regression analyses in which the independent variables were the lactating time (*Lact*: month), average temperatures of each month (*Temp*: ℃) and their square ($Temp^2$); the dependent variable was *GEE* for milk yields, body retention and heat production, respectively (Table 2). The adaptation of multiple regression formulas to the data was highest in *GEE* for milk (r=0.4286). No differences among calving numbers were clearly detectable in the regression coefficients to lactating times in the formulas of milk yields and heat production, but the coefficients in the formulas of body retention decreased with increasing calving numbers (first calving 0.56, second 0.61, third and forth 0.49 and fifth or later 0.32).

DISCUSSION

During the lactating period, variations in milk yields from diet (mj/mbs/day) depend on the characteristic changes in both metabolizable energy allowance (*MEa*: mj/mbs/day) and in the gross energetic efficiency (*GEE*: %) for milk. The results in this paper showed that both the *MEa* and *GEE* for milk decreased with longer lactating times. The variations corresponded with changes in milk energy during lactation. Everson et al.[7], Flatt8) and Naito et al.[9] also reported decreases in *GEE* for milk during lactation. We previously showed that there was a positive correlation between the milk energy and *MEa* in a cow herd, also reporting that no correlation was found between *MEa* and *GEE* for milk[2]. Therefore, we tend to think that the variations in milk yields during lactation are caused by independent changes in *MEa* and *GEE* for milk.

Milk yields per metabolic body size (mj/mbs/day) increased with calving numbers. This increase had probably been caused by the difference in *MEa* among the calving numbers rather than by that in *GEE* for milk. Naito et al.[9] stated that *GEE* for milk rose from the first to third calving, but that these differences were not remarkable. In this paper, no differences among calving numbers of *GEE* for milk were shown, except for that of the first calving which was slightly lower than those of other calving numbers. On the other hand, the metabolizable energy allowance increased with calving numbers.

Body retention (mj/mbs/day) from diet rose in the fifth or sixth month of lactation, and held steady thereafter. Everson et al.[7] also showed that the changes in body weight up to twenty-one weeks in a lactation period were negative, whereas those from twenty-two to forty-four weeks were positive. We think that this positive level was occurred due to increases in the gross energetic efficiency for body retention during lactation; since this level occurred despite the decline in *MEa* during that period. Greeve et al.[10] showed that there was a negative correlation between a cows' roughage intake and body weight gain during lactation, and that the intake per body weight gain decreased with the passage of lactating time. Flatt[8] then showed that *GEE* for body tissue rose as lactating time passed. Judging from these findings, it seems reasonable to suppose that body gains during the latter half of lactation were maintained by increases in *GEE* for body retention.

In a low calving number, although the metabolizable energy allowance (*MEa*) was small, the gross energetic efficiency (*GEE*: %) for body retention was high. From the result of this research which found that body retention is higher the younger a cow is, we speculate that differences in body gain or loss among calving numbers is independent of the differences in *GEE* for body retention based on a cow's ages. It seems likely that the rate of conversion from *MEa* to body retention rises when cows are young, but there is not much evidence to clarify the matter.

As for the metabolizable energy intake (*MEa*) and each gross energetic efficiency (*GEE*: %), this research showed that the lactating period influenced both, and that calving numbers influenced energy intake. We previously carried out a multiple regression analysis between air temperatures and *GEE* [2], showing the fitness of the correlation coefficients: r=0.2570~0.3795. The values in that report are lower than those (r=0.3125~0.4286) in this paper in which both air temperatures and lactating time were adopted as independent variables. Consequently, we conclude that the production efficiency in lactating cows was more affected by lactation time than by air temperature. Moreover, it is obvious that *GEE* for milk is particularly influenced by the lactation period as seen in the comparison among correlation coefficients of multiple regression formulas for each *GEE*. When raising the dairy cows, therefore, attention must be paid not only to diet allowance but also to the influence of lactation on production efficiencies.

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ホルスタイン泌乳牛群における飼料から生産への エネルギー流の泌乳期間中の動態とそれに産次が及ぼす影響

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要　　約

本論文の目的は、泌乳牛のエネルギー収支の各産次における泌乳期間中の変動を明らかにすることである。九年間にわたり飼養された泌乳牛の給与飼料量、乳量、乳脂率、体重のデータを使うことによって、各個体の代謝体重当たりの代謝エネルギー給与量、飼料由来の泌乳・体蓄積・熱発生量（各々mj/mbs/day）とそれらの総効率（%）を算出した。求められた値を泌乳期間中の変動として表し、産次間で比較した。結果は以下の通りである。1. 代謝エネルギー給与量・泌乳・熱発生量は高産次ほど高い。2. 体蓄積エネルギーとそれへの総効率は高産次ほど低い。3. 泌乳と消費のための総効率に産次間差はみられない。4. 代謝エネルギー給与量、泌乳・熱発生量・泌乳のための総効率は泌乳期1・2カ月以降減少する。5. 体蓄積エネルギーは泌乳期5・6カ月に上昇しそれ以降停滞する。6. 体蓄積のための総効率は泌乳期5～6カ月以降、熱発生のための総効率は泌乳期1・2カ月以降上昇する。7. 泌乳のための総効率は他の2つの総効率に比べて泌乳期の影響を強く受ける。以上の結果は、代謝エネルギー摂取量と各総効率には泌乳期特有の変動が存在すること、それらが泌乳期間中のエネルギー収支、特に泌乳エネルギーに強く影響していることを示した。

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