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Energy Metabolism of Calf

Junjiro SEKINE* and Yasushi ASAHIDA

Abstract
Energy metabolism of growing calves was subjected to analyses on the basis of available data mainly obtained from more than 800 determinations on 178 Holstein calves investigated by the group of Feeds and Feeding Laboratory, Hokkaido University. Calves in preruminant stage efficiently utilized metabolizable energy (ME) provided they were supplied energy by liquid feed consisting of over 70% of their diet. The efficiency of utilization of ME by suckling and weaning calves was governed by the proportion of energy supply from liquid feed in a ration. Fasting heat production was 385 $kJ/kg^{0.75}$ · day for ruminant calves at 4 to 6 months of age. Heat production showed a seasonal variation with a greater intensity in younger calves. The digestibility of nutrients and metabolizability of energy were both influenced by the quantity and quality of roughage in a ration for calves. Thus, supplementary concentrate is essential, and an addition of 60% of the concentrate in a ration is recommended to achieve a satisfactory weight gain of calves less than 13 weeks of age. The efficiency of utilization of ME was 0.75 for maintenance and 0.5 to 0.6 for growth of young calves. Requirements of ME were estimated to be around 500 $kJ/kg^{0.75}$ for maintenance and 510 to 520 $kJ/kg^{0.75}$ for 1 kg of weight gain.

Discipline: Animal industry
Additional key words: energy requirements, feed utilization, heat production, nutritive value of calf feed

Introduction

A long time has elapsed since an early weaning system has been recommended for rearing young calves. There is, however, a shortage of information available as a guidance to estimate adequately energy requirements for early weaned calves. In regard to the issues relating to calf nutrition, a majority of the studies so far undertaken have focused attention mainly to the utilization of protein. This paper places greater emphasis on the energy metabolism of growing calves.

Preruminant calf

1) Suckling period

An energy value of whole milk has long been evaluated on the basis of milk fat contents. In predicting precisely the energy value of milk, however, contents of protein and lactose also should be considered. The following equation is practically available to predict an energy value of milk with high accuracy[15]:

$$\text{Energy (MJ/kg of milk)} = 0.343 \cdot \text{fat (\%)} + 0.199 \cdot \text{SNF (\%)} + 0.005.$$

In case where the energy supply of whole milk varied in the range from approximately 40 to 70%, the efficiency of utilization of metabolizable energy for growth (kg) was estimated to vary from 0.51 ± 0.04[6] to 0.62 ± 0.04[14] in calves at the age of 2 to 6 weeks. When the milk replacer supplied accounts for about 81% of the total dietary energy, the calves metabolized energy at a rate of 0.882, and utilized metabolizable energy (ME) that had been ingested above maintenance at a rate of 0.72[29]. The kg is likely to vary with differences in the proportion of energy supply of liquid feed to the dietary energy.

Faculty of Agriculture, Hokkaido University (Sapporo, 060 Japan)
* Present address: Faculty of Agriculture, Tottori University (Tottori, 680 Japan)

2) Weaning period

The energy metabolism of calves during the weaning period is recognized to be most critical because they are in the transitional period from liquid diet to solid feed for subsistence. The *kg* was 0.69 ± 0.09 at the age of 6–7 weeks, when the calves took approximately 50% of the dietary energy from a milk replacer, and the metabolizability of energy (q) was 0.75[30]. Vermorel et al.[34] found that the Friesian calves of 10-week-old given a milk substitute diet utilized ME for growth (MEg) with the efficiency of 0.507 ± 0.033. Those calves obtained 22% of their dietary energy from the milk substitute and q was 0.697 on an average[34]. The *kg* appears to be also governed by the proportion of energy supply from the liquid feed given in the weaning period.

Ruminant calf

1) Fasting heat production

Fasting heat production has been alternatively substituted for the metabolism in the postabsorptive state of ruminants. Determination of composition of ruminal gas phase gives a simple and easy way to identify the state[33]. The changes in compositions of ruminal gas indicated that a 4-day-fasting satisfied to reach the quasi-postabsorptive stage in calves at the age of 4–6 months (Fig. 1)[16]. Fasting heat production of calves at this age was estimated to be 385 ± 11 kJ/kg$^{0.75}$·day[16].

2) Seasonal variation of heat production

It is generally recognized that animals ingest more feeds in the cold season than in the warm season. This phenomenon directly relates to energy expenditure of animals. Thus, energy requirement of the ruminants is influenced by a seasonal variation of the energy expenditure. It is reported that growing calves rapidly increased the rates of their heat production (HP) as they grew up during the age period 7- to 11-week-old[4]. Beyond 13 weeks old, the HP held a constant rate per unit of metabolic body size. The heat production, however, correlated negatively with the variation in barn temperature. Such a response of HP to temperature decreased its magnitude as the calves grew older: the calves over 13-week-old kept the same level of response to the change in barn temperature. This implies that adaptability of growing calves to the temperature variation in environment may be established before the age of 13 weeks old. Seasonal variation in HP of growing calves up to 25 weeks of age could be estimated by the optimum approximate cosine equations based on the least square spectrum procedure as shown in Tables 1 and 2[4].

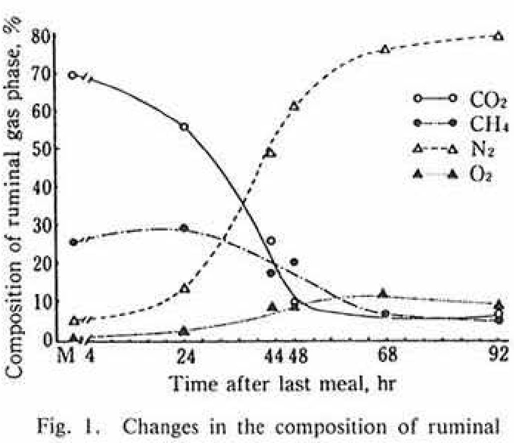

Fig. 1. Changes in the composition of ruminal gas phase in the course of fasting
M: At maintenance level of feeding.

3) Digestibility and nutritional values of calf feed

(1) Digestibility of early weaned calves

Energy digestibility correlates closely with digestibility of dry matter (DM) and organic matter (OM)[31]. It is reported that early weaned calves decreased DM or OM digestibility by 4 to 7% units in the intake of over 1 kg/day of the first cut hay of orchardgrass, while in the second cut hay of orchardgrass or alfalfa hay feeding, digestibility decreased to a small extent, or 1 to 2% units, in the intake over 1 kg/day[10]. The intake over 2 kg/day of the second cut hay or alfalfa hay, however, suppressed 3 to 4% units of DM and OM digestibilities[10].

It seems that calves digest DM and OM with almost the same efficiency up to 25-week-old, if the ration contains the same ratio of hay to concentrate[10]. The efficiency of digestion decreases as the ratio of hay to concentrate increases[5,13]. Changes in the ratios of hay to concentrate accompany an associative effect of digestibilities of energy and protein (Figs. 2 and 3)[20]. Digestible protein influences on quantities of energy retained by growing calves together with digestible nitrogen free OM[27]. Crude protein digestibility correlates positively with DM intake as well as with crude protein

Table 1. Optimum approximate cosine equations for seasonal changes in heat production

Age (week)	Samples (n)	OACE: $Y = M + A\cos(\omega t + \phi)$[1]	2 × A/M (%)	P (%)
7	7	$Y = 625 + 82.1\cos(\omega t - 17.7°)$	26.3	15.2
9	9	$Y = 682 + 38.2\cos(\omega t - 320.8°)$	11.2	19.8
11	12	$Y = 689 + 41.0\cos(\omega t - 301.0°)$	11.9	11.6
13–25	38	$Y = 723 + 23.6\cos(\omega t - 339.2°)$	6.5	5.2

1): Abbreviated notations are as follows:
OACE; Optimum approximate cosine equations, Y; Heat production ($kJ/kg^{0.75}\cdot day$), M; Mesor, A; Amplitude, ω; 360°/365, t; Days after the beginning of the year, ϕ; Acrophase.

Table 2. Optimum approximate cosine equations for seasonal changes in resting heat production

Age (week)	Samples (n)	OACE: $Y^{1)} = M + 4.3\cos(\omega t + \phi)^{2)}$	2 × A/M (%)	P (%)
7	7	$Y = 24.3 + 4.3\cos(\omega t - 30.4°)$	35.4	5.1
9	8	$Y = 26.6 + 3.1\cos(\omega t - 24.4°)$	23.3	33.1
11	12	$Y = 25.2 + 2.0\cos(\omega t - 305.7°)$	15.9	17.8
13–25	37	$Y = 26.4 + 0.9\cos(\omega t - 0.9°)$	6.8	21.3

1): Y; Resting heat production ($kJ/kg^{0.75}\cdot hr$),
2): All abbreviated notations except Y are shown in the footnote for Table 1.

content in a ration. It is predictable by employing the following multiple regression equation:

$$CPdig = -15.7\cdot HR + 0.88\cdot CP + 0.182\cdot DMI + 42.7,$$
$$R = 0.857 \pm 0.68,$$

where CPdig, HR, CP and DMI represent crude protein digestibility (%), hay ratio in a ration, crude protein content (%) and dry matter intake ($g/kg^{0.75}$)[25]. Efficiency of the utilization of protein is related to the quality of protein and digestion in the lower gut. Studies on nitrogen utilization of ruminant calves fitted re-entrant cannula in the duodenum showed that protein source influenced quantities of the nitrogen ingested in the duodenum and amounts digested in the lower gut[7-9].

Protein supplements induce diverse degradability of protein in the rumen[11]. It is suggested that the protein degradability in a mixed ration be influenced by the state of ruminal fermentation in growing calves[24]. A study on small ruminants showed a higher protein degradability taking place in the feeding of hay alone than in the case of rations containing different levels of hay and concentrate[1]. In analysing nitrogen digestion dynamics, further investigations on the relationship between the development of the rumen and the composition of rations for calves are required.

Digestibility of fiber as an energy source for ruminant calves also relates to a hay content in a ration. Contrary to the case in energy and protein, digestibility of neutral detergent fiber (NDF) is improved as the hay content in a ration increases (Fig. 4). Digestibilities of the first and second cut hays of orchardgrass were 53 and 60%, respectively in 6-month-old calves[20]. Digestibilities of the similar grass hays determined by mature wethers were 56 and 66% for the first and second cut hays, respectively[18]. Ruminal digestion rate constants of NDF were lower in calves up to 17-week-old than those steers of 14-month-old[12]. The potentially digestible portion of fiber was also about 10% less in calves than steers[12]. This means that ability of calves to utilize fiber might be inferior to that of mature ruminants. In addition, quantity of methane was generated with a much greater rate from NDF digested than cellular contents in calves up to the age of 25-week-old[21]. Therefore, energy supply by the fibrous fraction of a ration is likely to be smaller in the growing calves than the matured.

(2) Nutritive values of feed for calf

It is a general recommendation in calf feeding described in text books that such a good quality hay as the second cut hay should be given *ad libitum*.

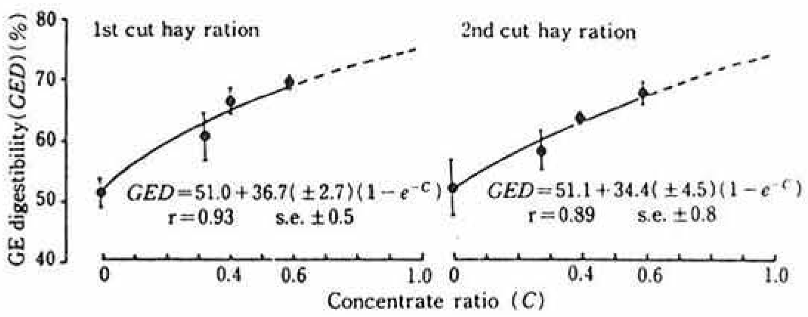

Fig. 2. Changes with concentrate ratio of a ration in coefficients of digestibility for gross energy (GED) in the ration

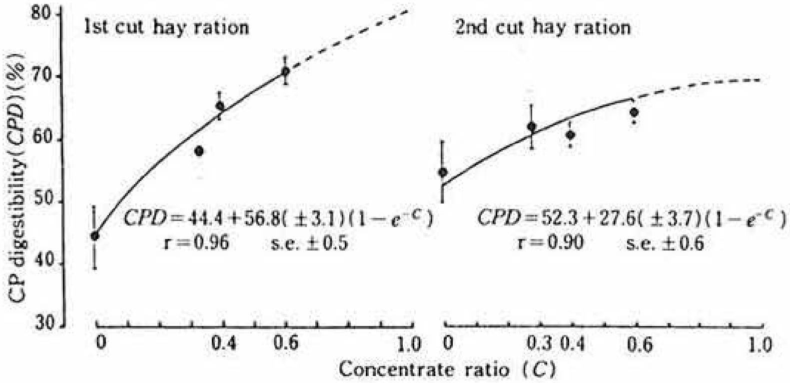

Fig. 3. Changes with concentrate ratio of a ration in coefficients of digestibility for crude protein (CPD) in the ration

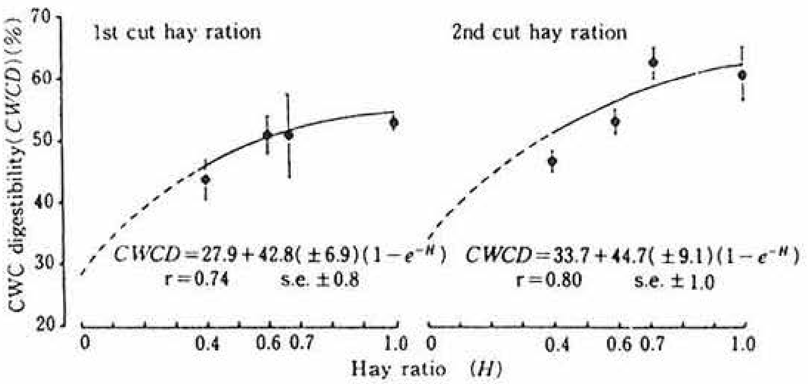

Fig. 4. Changes with hay ratio of a ration in coefficients of digestibility for cell wall constituents (CWCD) in the ration

None of them, however, has shown what a good quality is. As far as quality of the feed is concerned, protein and energy contents may be major components. The report[2] indicates that when calves were given the first cut hay, the second cut hay of orchardgrass or cubed alfalfa hay *ad libitum* with an addition of limited amount of calf starter, there was no difference in live weight gain, *q* value and efficiency of nitrogen utilization, even though the first cut hay was somewhat less preferable to the calves compared with the second cut hay and the alfalfa hay. Furthermore, nitrogen loss through urine increased in alfalfa hay diet[2]. An increased nitrogen content in urine leads to an increased loss of digested energy from the body reserve[23]. Thus, a higher content of protein in hay may not always be advantageous to calves.

A study was conducted to evaluate nutritive values of mixed feeding stuffs, specifically the first and the second cut hays of orchardgrass mixed with the concentrate at a constant ratio; i.e. concentrate: hay was 60:40 up to 13-week-old and 40:60 from 17- to 25-week-old. The result showed no significant difference among these stuffs in *q* value and efficiency of nitrogen retention[3]. This indicates that the first cut hay is adequate for use as a feeding stuff for calves, provides that protein is properly added in a ration.

Energy values varied among the orchardgrass first and second cut hays given to calves as a sole diet[31]. In a mixed ration of these hays, energy values appeared to be the same as those of the individual hay diets, and significantly increased as the proportion of concentrate increased in a ration (Fig. 5)[22]. This result indicates that in case where a large quantity of bulky feed is not available to consume, calves require a supplementary stuff of concentrate with a higher energy content in a ration. On the basis of the calf performances observed, it is recommended that proportion of the concentrate is 60% of the total ration for an infant calf less than 13-week-old.

4) Efficiency of utilization of metabolizable energy

(1) Maintenance

To improve energy utilization of calves, it is important to estimate ME required for maintenance (MEm) and its efficiency of utilization (*km*) under various feeding conditions. When ruminant calves at the age of 4 to 8 months were fed with rations containing 40% of orchardgrass first cut hay and 60% of calf starter, *km* was 0.747±0.018[17]. The *km* for 5-month-old calves was estimated to be 0.73[19]. It may be concluded that ruminant calves at the age of 4 to 6 months have *km* of approximately 0.75.

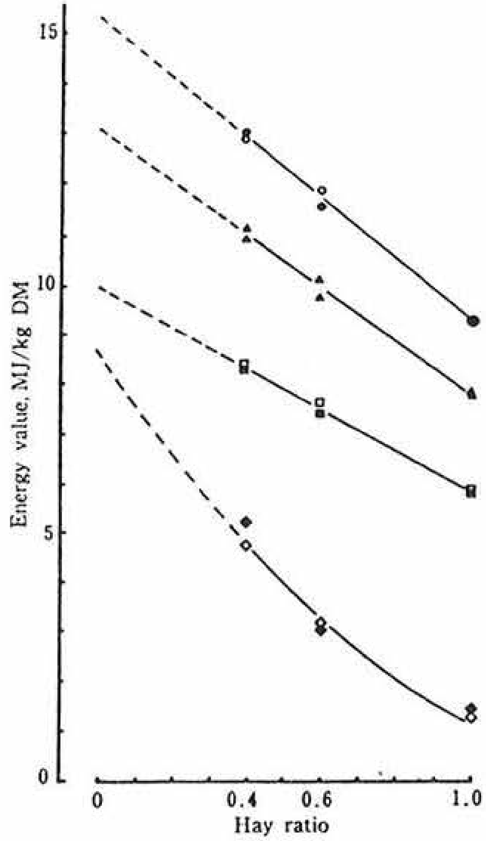

Fig. 5. Relationships between hay ratio and values of DE (○, ●), ME (△, ▲), NEm (□, ■) and NEg (◇, ◆) of the first (open symbol) and the second cut hay (solid symbol) rations

(2) Growth

From the results of surveys on mature ruminants, it is likely that their *kg* values might be lower than those of young ruminant calves. Calves with the weight of 55 to 99 kg utilized MEg with efficiency of 0.516±0.039[26]. The values of *kg* in calves with the weight of 100–149 kg and 150–195 kg were estimated to be 0.470±0.058 and 0.362±0.058, respectively[26]. In calves with the weight of 64 kg at the age of 7 weeks to 89 kg at 13 weeks, *kg* was estimated to be 0.500±0.023[32]. The results obtained in calves fed with rations containing different levels of rumen degradable protein (RDP) showed that there was no significant difference among the calves in *kg* value, which was 0.56±0.04 on an average, irrespective of the levels of the RDP in the ration[28].

The same value was obtained in the calves with the weight of 80–90 kg at 12- to 13-week-old. The *kg* for early weaned calves up to the age of 17 weeks was not affected by age and averaged 0.60 ± 0.04[27]. For those with the weight of 96–108 kg, *kg* resulted in 0.446 ± 0.032[19]. From the above-mentioned results, it is concluded that *kg* in ruminant calves with the weight of less than 100 kg ranges from 0.5 to 0.6 and that it may go down to the level of 0.4 when the calves grow old with the weight of over 100 kg.

Energy requirement of calf

1) *Maintenance*

It is reported that in the suckling period, calves require MEm of 476[14] and 482[6] $kJ/kg^{0.75}$. Another report indicates that the requirement of MEm is 458 $kJ/kg^{0.75}$ when the measurement is taken with milk-replacer-fed calves[29]. It is also presented that the required MEm increases during the weaning period up to 575 $kJ/kg^{0.75}$ [30]. Such a variation might be caused by adaptive alteration of metabolic process in the transitional period from liquid diet to solid feed for subsistence.

In the young ruminant calves with various ages of up to 25-week-old, there were no significant variations regarding the values of MEm. The estimates of MEm were 420[32], 555[28], 522[17], 528[19] and 521 $kJ/kg^{0.75}$ [17] for calves at various ages. The calves with the weight of 55–99 kg required 438 $kJ/kg^{0.75}$ of MEm, while those calves with the weight of 100–149 kg and 150–195 kg showed 483 and 513 $kJ/kg^{0.75}$ of MEm requirement, respectively[26]. It is concluded that the MEm requirements for preruminant and ruminant calves are approximately 480 and 500 $kJ/kg^{0.75}$, respectively.

2) *Growth*

In suckling calves given a milk replacer, it was estimated that one-kilogram of average daily gain (ADG) in weight required 413 $kJ/kg^{0.75}$ of MEg[29]. The measurements on energy metabolism were taken with milk-replacer-fed calves which had gained 0.5 kg/day[29]. The result may therefore not be directly applicable to those calves with a higher ADG than 0.5 kg. The study on MEg of weaning calves reveals that the MEg required for weaning calves may be 420 $kJ/kg^{0.75}$ at the most[30].

In regard to ruminant calves, MEg required for one-kilogram of ADG was estimated to be 520 ± 21, 575 ± 25 and 483 ± 24 $kJ/kg^{0.75}$ for those calves with the weight of 55–99 kg, 100–149 kg and 150–195 kg, respectively[26]. The calves at the age of 7, 9 and 13 weeks required 510 $kJ/kg^{0.75}$ [32]. The surplus of ME intake over MEm regressed through the origin on ADG for calves weighing less than 100 kg. The regression analysis resulted in 508 $kJ/kg^{0.75}$ for 1 kg daily gain[32].

It is reported that the estimated daily requirements of ME for growing ruminant calves fitted well the results based on the equation of British system, provided that their weight was over 100 kg, while for those calves with the weight of less than 100 kg, a lower ME requirement was estimated than the calculated one (Fig. 6)[32].

From those results as stated above, it may be concluded that the MEg requirement is 510–520 $kJ/kg^{0.75}$ per kilogram of ADG for ruminant calves with the weight of less than 100 kg, and that it may be more than 520 $kJ/kg^{0.75}$ for those over 100 kg since a lower efficiency of utilization of MEg is presumed.

Studies on energy metabolism of growing calves referred to the present report cover a limited range of feeding situations. The feeding stuffs under those studies consist mainly of hay and calf starter with several ratios in the mixture. In view of the availability of diverse alternatives of feeding materials, including inferior quality feed resources, further studies

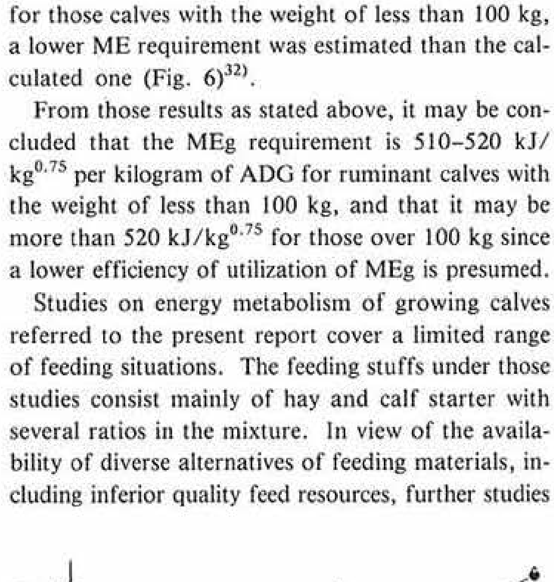

Fig. 6. Metabolizable energy (ME) requirements to support 0.8 kg/day live weight gain in growing calves estimated by the results reported by Sekine et al. (1989: ○), Sekine et al. (1987: ●), ARC (1980: △) and NRC (1978: ▲)

on energy metabolism in the early stage of growth of ruminant calves are required.

References

1) Inoue, Y. et al. (1989): Effect of ratio of concentrate to roughage on the rumen degradability of crude protein in Italian ryegrass and cubed alfalfa hays. *Asian-Australasian J. Anim. Sci.*, **2**, 409–410
2) Kobayashi, Y. et al. (1982): Evaluation of hays for early weaned calves. *Jpn. J. Zootech. Sci.*, **53**, 729–735 [In Japanese with English summary].
3) Kobayashi, Y. et al. (1982): Evaluation of orchardgrass hays in mixed diet for early weaned calves. *Jpn. J. Zootech. Sci.*, **53**, 736–742 [In Japanese with English summary].
4) Morooka, T. et al. (1983): Seasonal changes in heat production of calves growing from 7 to 25 weeks of age under housing conditions. *Jpn. J. Livestock Management*, **18**, 81–87 [In Japanese with English summary].
5) Morooka, T. et al. (1986): Energy digestibility of 16-week-weaned calves from 9 to 25 weeks of age. *J. Fac. Agr. Hokkaido Univ.*, **63**, 114–118.
6) Morooka, T. et al. (1988): Utilization of metabolizable energy in suckling and 6-week-weaned growing calves. *In* Proc. 6th World Cong. Anim. Prod., 423.
7) Obitsu, T. et al. (1986): A note on fitting re-entrant cannulae on the duodenum of growing young calves for determining of site and extent of utilization of nitrogen. *J. Fac. Agr. Hokkaido Univ.*, **62**, 384–387.
8) Obitsu, T. et al. (1986): Comparison of the continuous and spot sampling methods for collecting digesta of the duodenum in young calves fitted with the duodenal re-entrant cannulae. *J. Fac. Agr. Hokkaido Univ.*, **63**, 58–63.
9) Obitsu, T. et al. (1986): A preliminary study on nitrogen utilization in growing calves fitted with re-entrant duodenal cannulae. *Jpn. J. Zootech. Sci.*, **57**, 1041–1042 [In Japanese].
10) Okubo, M. et al. (1983): The effect of sources and proportions of hays in the ration on digestibility of weaned calves. *Res. Bull. Univ. Farm, Hokkaido Univ.*, **23**, 51–59 [In Japanese with English summary].
11) Okubo, M. et al. (1986): The rumen degradability of protein for various feedstuffs. *J. Fac. Agr. Hokkaido Univ.*, **63**, 49–53.
12) Oura, R. et al. (1987): Digestion kinetics of fibrous and soluble plant materials in the reticulo-rumen of early weaned calves from 7 to 17 weeks of age. *Jpn. J. Zootech. Sci.*, **58**, 797–804.
13) Sekine, J. et al. (1981): The effect of feeding levels of calf starter on ration utilization and performances of weaned calves. *Res. Bull. Univ. Farm, Hokkaido Univ.*, **22**, 66–72 [In Japanese with English summary].
14) Sekine, J. et al. (1983): Estimate of metabolizable energy requirements for maintenance and growth of growing calves weaned at six weeks of age. *In* Proc. 5th World Cong. Anim. Prod., **2**, 371–372.
15) Sekine, J. et al. (1985): Prediction of the energy value of cow's milk from the concentration of its components. *Jpn. J. Zootech. Sci.*, **56**, 583–587 [In Japanese with English summary].
16) Sekine, J. et al. (1985): Fasting heat production of calves at 4 to 6 months of age. *Jpn. J. Zootech. Sci.*, **56**, 787–791 [In Japanese with English summary].
17) Sekine, J. et al. (1985): Determination of metabolizable energy required for the maintenance of growing calves at 4 and 6 months of age. *Jpn. J. Zootech. Sci.*, **56**, 920–924 [In Japanese with English summary].
18) Sekine, J. et al. (1985): Assessment of nutritional values of orchardgrass hay. *Res. Bull. Univ. Farm, Hokkaido Univ.*, **24**, 63–67 [In Japanese with English summary].
19) Sekine, J. et al. (1986): Efficiency of energy utilization by growing calves on realimentation after fasting. *Jpn. J. Zootech. Sci.*, **57**, 126–130 [In Japanese with English summary].
20) Sekine, J. et al. (1986): Effect of hay: concentrate ratios on digestibility of a mixed ration for growing calves. *Jpn. J. Zootech. Sci.*, **57**, 231–236 [In Japanese with English summary].
21) Sekine, J. et at. (1986): Estimation of methane production in 6-week-weaned calves up to 25 weeks of age. *Jpn. J. Zootech. Sci.*, **57**, 300–304 [In Japanese with English summary].
22) Sekine, J. et al. (1986): Evaluation of energy values of orchardgrass hay and a mixed ration for 6-month-old calves. *Jpn. J. Zootech. Sci.*, **57**, 485–490 [In Japanese with English summary].
23) Sekine, J. et al. (1986): A note on estimation of urinary energy from nitrogen content of urine in early weaned calves up to 6 months of age. *Jpn. J. Zootech. Sci.*, **57**, 620–623.
24) Sekine, J. et al. (1986): Some considerations on estimating a value of the rumen degradability of protein of the mixed ration for early weaned calves from the values of ingredients. *J. Fac. Agr. Hokkaido Univ.*, **63**, 54–57.
25) Sekine, J. et al. (1986): Effects of crude protein content, dry-matter intake and hay ratio on digestibility of crude protein in a mixed ration for growing calves. *J. Fac. Agr. Hokkaido Univ.*, **62**, 349–353.
26) Sekine, J. et. al. (1987): The estimation of metabolizable energy requirements for maintenance and growth of growing calves weaned at six weeks of age. *Jpn. J. Zootech. Sci.*, **58**, 266–272.
27) Sekine, J. et al. (1987): Energy supply of dietary nutrients and utilization of energy and nitrogen by early weaned calves up to 17 weeks of age. *Jpn. J. Zootech. Sci.*, **58**, 864–870.
28) Sekine, J. et al. (1988): Energy metabolism of growing calves fed a ration containing different levels of rumen degradable protein. *In* Proc. 6th World Cong. Anim. Prod., 382.

29) Sekine, J. et al. (1988): Metabolizable energy requirements for maintenance and growth of suckling calves given milk replacer. *Asian-Australasian J. Anim. Sci.*, **1**, 61–63.
30) Sekine, J. et al. (1988): The efficiency of utilization of metabolizable energy of milk-replacer-fed calves at weaning period. *Asian-Australasian J. Anim. Sci.*, **1**, 185–187.
31) Sekine, J. et al. (1989): Energy values of orchardgrass hay for growing calves. *Jpn. J. Zootech. Sci.*, **60**, 286–291.
32) Sekine, J. et al. (1989): Effect of age on energy utilization of early weaned growing calves weighing less than 100 kg. *Anim. Prod.*, **48**, 75–79.
33) Sumio, Y. et al. (1983): Collection of rumen gases from young calves. *Jpn. J. Zootech. Sci.*, **54**, 60–61 [In Japanese].
34) Vermorel, M. et al. (1980): Energy utilization by growing calves: Effects of age, milk intake and feeding level. *In* Energy Metabolism, ed. Mount, L. E., EAAP Pub. Butterworths, London, No. 26, 49–53.

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