Methane Production in Heifers, Sheep and Goats Consuming Diets of Various Hay-Concentrate Ratios

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(Received April 23, 1992)

Abstract Six Holstein heifers, 10 Corriedale wethers and 11 castrated male goats of Japanese native breed were used to clarify the effects of hay-concentrate ratios on methane (CH_4) production in heifers, sheep and goats, and to find a ready method for estimating CH_4 production of ruminants. The three levels of hay-concentrate were 100:0 (H100), 70:30 (H70), 30:70 (H30), which were offered to meet around 150% of total digestible nutrients requirements. The results were as follows: 1) CH_4 production was significantly different among animal species. Heifers produced about 7 times and 9 times as much as sheep and goats, respectively. 2) CH_4 production was also significantly different among treatments. CH_4 production in H30 treatment was significantly lower than that in H70 treatment. It was attributed to lower cellulose content and lower digestibility of fiber fractions caused by a high concentrate diet in the H30 treatment. 3) There were no significant differences in CH_4 production per various nutrient intakes among animals though their treatment effects were significant. 4) From the results of multiple regression analyses, the most useful predictors of CH_4 production were the amounts of nitrogen, crude fiber and nitrogen free effects intake or those apparently digested. 5) Although estimation by multiple regression equations was more precise, the simple regression equation with dry matter intake was also highly significant. 6) From the above results, it can be concluded that CH_4 production by ruminants below 1.5 times maintenance can be estimated adequately from dry matter intake (DMI) alone by the equation CH_4 (l/day) = $0.0305 \text{ DMI (g/day)} - 4.441$ ($r = 0.992$).

Anim. Sci. Technol. (Jpn.) 63 (12) : 1221-1227, 1992

Key words : methane production, hay-concentrate ratio, heifer, sheep, goat

Recently, the rise in concentrations of so-called "Greenhouse gases", including methane, in the atmosphere and resultant global warming have been pointed out as a serious problem. According to CRUTZEN *et al.*³⁾, current CH_4 emission by domestic and wild animals is estimated to be about 78 teragrams/yr (Tg,

$\text{g} \cdot 10^{12}$), representing 15-25% of the total CH_4 released into the atmosphere from all sources.

Among animals, ruminants are the major emitters of CH_4 . Therefore, methanogenesis within the rumen has been focused on in discussions regarding CH_4 emissions from animals. However, CH_4 production in ruminants is

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strongly influenced by the level and type of diet²⁾ and, therefore, the relationships between dietary factors and CH₄ production should be identified to estimate CH₄ production precisely in ruminants.

Several attempts have been made to predict energy losses as CH₄ by determining the amount of nutrients ingested or digested in cattle and sheep^{2,7,9,15,16)}. However, most of them require the measuring the amount of digested carbohydrate fractions for estimating CH₄ production. Therefore, it is difficult to use those prediction equations for estimating global CH₄ emission from ruminants by agricultural statistics. Furthermore, very few researches have dealt with cattle, sheep and goats simultaneously and tried to predict CH₄ production in ruminants feeding on various levels of hay-concentrate ratios.

Our objective was to clarify the effect of hay-concentrate ratios on CH₄ production in cattle, sheep and goats and to find a ready method for estimating CH₄ production of ruminants.

Materials and Methods

Six Holstein heifers, 10 Corriedale wethers and 11 castrated male goats of Japanese native breed were used. Sheep and goats were divided into 3 groups and allocated to each of 3 dietary treatments as shown in Table 1, while all heifers were used for 3 treatments repeatedly. The mean body weights of heifers, sheep and

goats were 401, 71 and 39 kg respectively.

Treatments consisted of three experimental diets. They were offered to meet around 150% of total digestible nutrients (TDN) requirements according to Japanese Feeding Standard¹²⁾ for heifers, NRC¹¹⁾ for sheep and according to ITOH *et al.*⁵⁾ for goats. The diets consisted of three proportions of hay wafer to concentrate : 100 : 0 (H 100), 70 : 30 (H 70), 30 : 70 (H 30). The hay used in this experiment consisted mainly of orchardgrass. The concentrate consisted of 30% milo, 20% barley, 20% corn, 10% wheat bran, 10% alfalfa meal, 5.5% molasses, 1% urea and 3.5% vitamins and minerals.

For regression analyses, goat data obtained from an extra period of 50 : 50 treatment (H 50) of hay to concentrate ratio were also used.

Animals were maintained on the experimental diets for 3 to 7 wks before a balance trial. The balance trial included a 7-day preliminary period, a 7-day metabolism trial with total collection of urine and feces and respiration measurements over 2 consecutive days in open circuit respiration chambers⁶⁾.

Proximate analyses were done for hay, concentrate, refused diet and feces by standard procedures. Starch and fiber fractions were done via procedures described by ABE¹⁾. The nutrient composition of the hay and concentrate are in Table 2.

Analyses of variance for all animals and

Table 1. Number of animals, mean body weight, hay-concentrate ratio and dry matter (DM) intake

Item	Heifers			Sheep			Goats		
	H100	H70	H30	H100	H70	H30	H100	H70	H30
Number of animals	6	6	6	4	3	3	4	4	3
Body Weight (kg)	384.6	397.3	420.7	69.1	70.3	73.2	39.1	39.9	38.0
Hay-concentrate ratio									
Hay wafer (% DM)	100.0	69.5	30.9	100.0	70.1	29.9	100.0	70.0	29.8
Concentrate (% DM)	—	30.5	69.1	—	29.9	70.1	—	30.0	70.2
DM intake (kg/day)	8.1	8.3	8.1	1.3	1.3	1.3	1.1	1.1	0.8

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Table 2. Chemical composition of hay and concentrate

	DM	CP	CF	NFE	NDF	ADF	STA
	% of DM						
Hay	88.19	12.94	29.02	42.86	60.78	36.96	1.18
Concentrate	86.55	15.02	5.59	69.07	14.03	8.41	48.61

DM : Dry matter, CP : Crude protein, CF : Crude fiber, NFE : Nitrogen free extracts, NDF : Neutral detergent fiber, ADF : Acid detergent fiber, STA : Starch.

treatments were conducted by the method of unequal numbers per cell without interaction of principal factors, and was done for each animal as one-way classification data. Both were computed by the library program of the Computing Centre for Research in Agriculture, Forestry and Fisheries^{13,14)}.

Results and Discussion

Significant treatment effects were found in the digestibilities of all components, except for starch digestibility which showed a value above 98% through all treatments. Digestibilities of dry matter (DM), nitrogen free extracts (NFE), crude fiber (CF) and neutral detergent fiber (NDF) are presented in Table 3. DM digestibility increased significantly by increasing the proportion of concentrate for all animal species. This increase was mainly attributed to the increase in the digestibility of NFE. In contrast to DM and NFE, NDF digestibility significantly decreased in heifers and sheep as the level of concentrate increased. However,

there was no significant reduction in goats between H 100 and H 70. It is generally recognized that increases in the fiber content of diets cause a decrease in the digestibility of most components of the diet except the fiber itself and the addition of starch depressed cellulolysis¹⁰⁾. It is clear that the marked decrease in NDF digestibility in H 30 treatment was caused by high starch intake.

Table 4 shows the least square means for oxygen (O₂) consumption, and carbon dioxide (CO₂), heat and CH₄ production. O₂ consumption per metabolic body size (MBS, BW kg^{0.75}) differed significantly among animal species as did CO₂ and heat production, although no significant difference among treatments was detected. Heifers showed significantly higher values. They consumed O₂ and produced CO₂ and heat about 55% more per unit MBS than both sheep and goats. However, those values for both sheep and goats showed close agreement.

CH₄ production was significantly different

Table 3. Digestibility of dry matter and proximate components of diets

	Heifers			Treat- ment effects	Sheep			Treat- ment effects	Goats			Treat- ment effects
	H100	H70	H30		H100	H70	H30		H100	H70	H30	
DM	61.9 ^a	66.1 ^b	69.0 ^c	**	62.6 ^a	65.9 ^b	72.3 ^c	**	61.4 ^a	64.9 ^a	72.6 ^b	**
NFE	70.2 ^a	77.1 ^b	80.9 ^c	**	69.6 ^a	75.1 ^b	81.7 ^c	**	68.1 ^a	74.5 ^b	82.3 ^c	**
CF	59.2 ^a	56.3 ^a	47.8 ^b	**	56.1 ^a	53.4 ^a	44.4 ^b	**	53.5 ^a	53.2 ^a	42.7 ^b	*
NDF	66.2 ^a	62.5 ^b	49.1 ^c	**	65.2 ^a	60.4 ^a	48.0 ^c	**	63.3 ^a	60.3 ^a	46.6 ^b	**

¹⁾ DM, NFE, CF, NDF : See footnote in Table 2.

²⁾ Level of significance : **P<0.01; *P<0.05.

³⁾ a, b, c : Means in the same row within each animal with different superscripts differ (P<0.05) by Student's t test.

Table 4. Least square means for daily oxygen consumption (O_2), and carbon dioxide (CO_2), heat and methane (CH_4) production

Item	Animal			Treatment			Difference among anim treat	
	Heifers	Sheep	Goats	H100	H70	H30		
O_2 /MBS ($l/kg^{0.75}$)	34.0 ^a	22.0 ^b	21.8 ^b	26.3	26.3	25.2	**	NS
CO_2 /MBS ($l/kg^{0.75}$)	35.6 ^a	22.4 ^b	23.4 ^b	26.7	27.9	26.8	**	NS
Heat/MBS ($kJ/kg^{0.75}$)	719.1 ^a	461.6 ^b	462.0 ^b	550.9	556.9	534.9	**	NS
CH_4 (l)	230.9 ^a	34.3 ^b	25.2 ^b	93.0 ^{a, b}	115.0 ^a	82.5 ^b	**	*
CH_4 /MBS ($l/kg^{0.75}$)	2.6 ^a	1.4 ^b	1.7 ^b	1.9 ^{a, b}	2.2 ^a	1.6 ^b	**	**
CH_4 /DM (l/kg)	28.4	25.9	27.1	26.0 ^{a, b}	29.9 ^a	25.4 ^b	NS	*
CH_4 /CF (l/kg)	148.1	132.2	147.8	90.2 ^a	135.2 ^a	202.8 ^b	NS	**
CH_4 /NFE (l/kg)	56.6	51.9	53.3	61.6 ^a	59.1 ^a	41.1 ^b	NS	**

¹⁾ MBS : Metabolic body size (Body weight $kg^{0.75}$).

²⁾ DM, CF, NFE : See footnote in Table 2.

³⁾ Level of significance : NS Not significant; ** $P < 0.01$; * $P < 0.05$.

⁴⁾ a, b : Means in the same row within animal and within treatment with different superscripts differ ($P < 0.05$) by Student's *t* test.

among animal species. Heifers produced about 7 times and 9 times as much as sheep and goats, respectively. In a report by GIBBS *et al.*⁴⁾, the total population of cattle, buffalo, goats and sheep was combined into "Livestock units" using the following population multipliers : cattle = 0.8 ; sheep = 0.1 ; goats = 0.1. It can be considered that the multipliers for "Livestock units" described above are not far from our results and are reasonable values with which to discuss CH_4 emission from ruminants.

CH_4 production was also significantly different among treatments. CH_4 production in the H30 treatment was significantly lower than that in H70 treatment. It has been shown that the amount of digested cellulose contributed to CH_4 production more than that of other carbohydrate components⁹⁾. Since, moreover, the conditions that promote the synthesis of microbial cells and propionate production lead to reduced CH_4 production⁸⁾, it is considered that lower CH_4 production in H30 treatment was a result of lower cellulose content and lower digestibility of fiber fractions. Promoted propionate type fermentation, usually caused by a high concentrate diet, also

might be a factor in lower CH_4 production as LENG⁸⁾ pointed out.

There were no significant differences in CH_4 production per various nutrient intakes among animals though their treatment effects were significant. This confirms that CH_4 production is a function of the nutrient intake and not of the size of the animal. CH_4 production per DM intake showed its highest value in H70 treatment though no significant difference was detected between H70 and H100. CH_4 production per CF and NFE changed with the changes in the level of concentrate. The former showed a significantly higher value and the latter showed a significantly lower value in the H30 treatment over others. It is considered that no significant differences among the animals and significant differences among treatments allowed the possibility of estimating CH_4 production via nutrient intake for heifers, sheep and goats.

Table 5 summarizes the results of multiple regression analyses relating CH_4 production to various nutrient intakes. Since CH_4 is a product of the microbial fermentation of carbohydrates in the rumen and SEKINE *et al.*¹⁵⁾ found a negative relationship between DCP and

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Table 5. Results of regression analyses of methane production (l/day) on nutrients and digestible nutrients intake (g/day).

Regression equation	r ² or R ²	SE
CH ₄ = 0.0305 DM-4.441	98.4	13.6
CH ₄ = 0.0356 CF+0.0450 NFE-4.714	98.9	11.2
CH ₄ = 0.0476 NDF+0.0541 STA-4.642	98.8	11.6
CH ₄ = -0.980 N+0.0646 CF+0.0747 NFE-4.708	99.1	10.1
CH ₄ = 0.0470 DDM-5.364	99.1	10.1
CH ₄ = 0.0744 DCF+0.0552 DNFE-3.836	99.2	9.7
CH ₄ = 0.135 DADF+0.0620 DSTA-4.141	98.9	11.2
CH ₄ = -0.960 DN+0.0991 DCF+0.0756 DNFE-0.53	99.3	8.9

¹⁾ r² or R²: Coefficient of determination (% , adjusted for the degree of freedom).

²⁾ SE: Standard error of residuals.

³⁾ DM, CF, CP, NFE, NDF, STA: See footnote in Table 2.

⁴⁾ MBS: See footnote in Table 4.

⁵⁾ DDM: Digestible DM, DCF: Digestible CF, DNFE: Digestible NFE, DADF: Digestible ADF, DSTA: Digestible STA, N: Nitrogen, DN: Digestible N.

CH₄ production, analyses were done by both the backward elimination method and the forward selection method for intakes of DM, N and carbohydrate components such as CF and NFE or NDF, acid-detergent fiber (ADF) and starch (STA) as predictor variables. Analyses for digestible nutrient intakes were also done in the same manner.

All nutritional components had a significant positive correlation with CH₄ production ($r > 0.87$) although both STA and digestible starch (DSTA) intake had a low value ($r = 0.64$) compared with the other components. It is considered that CH₄ production is closely related to cellulose digestion. MOE and TYRRELL⁹⁾ found differences in the contribution of each carbohydrate component to CH₄ production in cattle. CH₄ production per gram of cellulose digested is nearly 3 times that per gram of hemicellulose digested and 5 times that per gram of soluble residue digested. SEKINE *et al.*¹⁵⁾ also concluded that the best predictor of CH₄ production in calves was amounts of digestible cellular contents and digestible cell wall constituents or digestible ADF. Our data also shows a precise estimate obtained from a multiple regression equation using each carbohydrate component. However,

unlike the results of SEKINE *et al.*¹⁵⁾, there was no improvement in the coefficient of determination and standard error of residuals by using carbohydrate components that were determined by the detergent method. The most useful predictor of CH₄ production is the amounts of N, CF and NFE intake or those apparently digested. The accuracy increased little when digestible nutrient intakes were used as predictors.

Although estimation by multiple regression equations is more precise, the simple regression equation with DM was also highly significant. Also, no improvement in estimation was observed when DM supplied by hay and by concentrate were used as predictors, although no data is presented in this paper. BLAXTER and CLAPPERTON²⁾ showed that estimation from the total amount of digested carbohydrates was open to error because CH₄ production was found to vary even when the amounts of digested carbohydrate were almost constant. KRISS⁷⁾ also found a linear relationship between CH₄ production and DM intake in cattle. According to MOE and TYRRELL⁹⁾, CH₄ production was not influenced as much by type of carbohydrate digested at low intake, such as below 1.5 times maintenance, as at higher

intakes. Since, in our experiment, feeding level was around 1.5 times maintenance for all animals, no effects due to the nature of carbohydrate components was observed.

From the above results, it can be concluded that CH_4 production by ruminants below 1.5 times maintenance can be estimated adequately from DM intake alone though a small increase in the coefficient of determination and a small decrease in the standard error of residuals will occur by using N, CF and NFE intake or those apparently digested as a predictor. Further investigation is needed for cattle fed poor quality roughage, for lactating cows fed above 1.5 times maintenance and for fattening cattle fed an extremely high concentrate diet.

Acknowledgement

The authors sincerely wish to thank Dr. T. HARYU, Head of Department of Animal Nutrition in our institute, for reviewing this manuscript.

References

- 1) ABE, A., Feed analyses based on the carbohydrates and its application to the nutritive value of feeds. Mem. Nat Inst. Anim. Ind. No. 2. 1988.
- 2) BLAXTER, K.L. and J.L. CLAPPERTON, Prediction of the amount of methane produced by ruminants. Br. J. Nutr., **19**: 511-522. 1965.
- 3) CRUTZEN, P.J., I. ASELMANN and W. SEILER, Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humans. Tellus, **38 B**: 271-284. 1986.
- 4) GIBBS, M.J., L. LEWIS and J.S. HOFFMAN, Reducing methane emissions from livestock: Opportunities and issues. U.S. EPA. EPA 400/1-89/002. Washington, D.C. 1989.
- 5) ITOH, M., T. HARYU, R. TANO and K. IWASAKI, Maintenance requirements of energy and protein for castrated Japanese native goats. Bull. Nat. Inst. Anim. Ind., **33**: 41-50. 1978.
- 6) IWASAKI, K., T. HARYU, R. TANO, F. TERADA, M. ITOH and K. KAMEOKA, New animal metabolism facility especially the description of respirational apparatus. Bull. Nat. Inst. Anim. Ind., **39**: 41-78. 1982.
- 7) KRISS, M., Quantitative relations of the dry matter of the food consumed, the heat production, the gaseous outgo, and the insensible loss in body weight of cattle. J. Agric. Res., **40**: 283-295. 1930.
- 8) LENG, R.A., Improving ruminant production and reducing methane emissions from ruminants by strategic supplementation. U.S. EPA. EPA 400/1-91/004. Washington, D.C. 1991.
- 9) MOE, P.W. and H.F. TYRRELL, Methane production in dairy cows. J. Dairy Sci., **62**: 1583-1586. 1979.
- 10) MOULD, F.L., Associative effects of feeds. in World animal science, B4, Feed science. (ØRSKOV, E.R., ed.) 279-292. Elsevier Sci. Publ. B.V. Amsterdam. 1988.
- 11) National Research Council, Nutrient requirements of sheep. 4th ed. National Academy of Sciences. Washington, D.C. 1968.
- 12) National Research Council of Agriculture, Forestry and Fishery, Japanese feeding standard for dairy cattle. Central Assoc. Livestock Ind. Tokyo. 1974.
- 13) NISHIDA, A., Analysis of two-way classification data with unequal subclass numbers—interaction negligible. Bull. Computing Centre Res. Agric. Forestry Fishery, **A 4**: 45-62. 1969.
- 14) OKUNO, C., Analysis of one-way classification data. Bull. Computing Centre Res. Agric. Forestry Fishery, **A 1**: 1-6. 1967.
- 15) SEKINE, J., S. KONDO, M. OKUBO and Y. ASAHIDA, Estimation of methane production in 6-week-weaned calves up to 25 weeks of age. Jpn. J. Zootech. Sci., **57**: 300-304. 1986.
- 16) SWIFT, R.W., J.W. BRATZLER, W.H. JAMES, A.D. TILLMAN and D.C. MEEK, The effect of dietary fat on utilization of the energy and protein of rations by sheep. J. Anim. Sci., **7**: 475-485. 1948.

牛，めん羊および山羊のメタン発生量に及ぼす 乾草と濃厚飼料給与比率の影響

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反芻家畜のメタン発生量に及ぼす乾草と濃厚飼料給与比率の影響を検討し，簡易なメタン発生量推定式の作成を試みた。供試動物は，ホルスタイン種未経産牛6頭，コリデール種成去勢雄めん羊10頭および日本在来種成去勢雄山羊11頭とした。給与飼料は，オーチャードグラス主体混播牧草を原料草とした乾草ウェハーおよび当該指定濃厚飼料（尿素1%入り，ペレット）であり，乾草と濃厚飼料の給与比率を乾物換算で100:0（H100），70:30（H70）および30:70（H30）とした3処理について実験を行なった。飼料給与量は，TDNで維持要求量の1.5倍を満足する量とした。その結果，次のような知見を得た。1）メタン発生量は，動物種間に有意差が認められ，牛の発生量はめん羊の7倍，山羊の9倍であった。2）メタン発生量は，H70処理にくらべてH30処理で有意に低い値を示した。これは，濃厚飼料多給に伴う飼料中のセルロース含量の低下，繊維成分消化率の低下等の要因に起因すると考えられた。3）各種栄養成分摂取量当りのメタン発生量は，処理間に有意差を認めたが，動物種間に有意な差は認められなかった。4）重回帰分析の結果，メタン発生量推定に対する最も有効な説明変数として，窒素，粗繊維および可溶無窒素物の摂取量あるいはそれらの可消化物摂取量が選択された。5）しかし，乾物摂取量（DMI）のみを説明変数として用いても推定精度の低下は小さく，TDNで維持の1.5倍程度の栄養水準における反芻家畜のメタン発生量の簡易な推定式として，以下の式が導出された。
メタン発生量（1/日）＝0.0305 DMI（g/日）－4.441（ $r=0.992$ ）。

日畜会報，63（12）：1221-1227，1992

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