Methane Production in Dairy Cows

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ABSTRACT

The relationship among diet composition, intake, and methane production was investigated with data during 404 total energy balance trials with Holstein cows. Methane production in all trials was measured in open circuit respiration chambers. The most useful predictor of total methane production was amounts of soluble residue, hemicellulose, and cellulose that apparently were digested. The regression was methane (Mcal) = .439 + .273 ± .015 kg digestible soluble residue + .512 ± .078 kg digestible hemicellulose + 1.393 ± .097 kg digestible cellulose.

INTRODUCTION

The systematic use of metabolizable energy (ME) to describe the energy of ruminant diets depends on either direct measurement of methane production or adequate means of estimating methane production. Because methane is a gaseous loss, its measurement requires specialized equipment. Therefore, the ME of many diets is estimated by calculated methane production. Kriss (7) found a linear relationship between methane production and dry matter intake of cattle. Bratzler and Forbes (2) with cattle and Swift et al. (14) with sheep identified a relationship between methane production and amount of carbohydrate apparently digested. Blaxter and Clapperton (1) concluded that methane production at maintenance by cattle and sheep could be described by the relationship: CH_4 (percentage of gross energy consumed) = 3.67 + .62 *digestible energy* (DE, %) and that the rate of change in percentage of gross energy lost as methane by an increase in intake equal to one times maintenance could be described by b = .054 DE(%) − 2.26 for mixed diets. Our objective was to identify the relationship between dietary carbohydrate and methane production in cattle ingesting diets at a substantially greater range of intake than in the studies cited.

EXPERIMENTAL PROCEDURE

The data are from 404 total energy balance trials with Holstein cows in experiments designed to study the following effects on the energy of dairy cattle diets: percentage of protein (8); proportion of concentrate (15); relative energy value of corn grain and barley (17), oats (12), beet pulp (16), dried brewers grains, and dried distillers grains (18), or wheat bran (10); the physical form of corn grain in the total diet (9, 13); or the incremental energy value of corn grain (11). The experimental procedures and diets are described in the individual reports.

Methane production was measured during three or four consecutive 24-h periods during each balance trial. An aliquot of air exhausting from the respiration chamber was collected continuously in a 10-liter spirometer (bell type) sealed with paraffin oil. Either two or three spirometers were used to collect replicate samples from each respiration chamber. The composition of chamber exhaust air collected in the spirometers was measured each day with an infrared analyzer previously calibrated with a reference gas mixture of known methane content. Methane energy was calculated from volume measurement by the factor 9.45 kcal/liter (3).

Chemical analyses of feeds and feces were based on the fiber methods of Goering and Van Soest (5). These included acid-detergent fiber (ADF), cell walls (neutral-detergent fiber, NDF), cellulose (ADF-lignin-silica), and hemicellulose (NDF-ADF). An additional fraction, soluble residue, was calculated by subtracting crude protein and ether extract from the neutral-detergent solubles. The soluble residue

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fraction thus contains the most soluble and readily fermentable or digestible carbohydrate and for the mixed diets studied here likely consists primarily of starch.

Statistical relationships were established by multiple regression analysis with the least squares methods of Harvey (6).

RESULTS AND DISCUSSION

The mean, standard deviation, and range of chemical composition, intake of carbohydrate components, and amounts apparently digested are in Table 1. The maximum amount of total carbohydrate digested was 11.5 kg/day which is approximately twice that of the study of Bratzler and Forbes (2).

A regression in which total methane production was related to intake of crude protein, ether extract, soluble residue, hemicellulose, cellulose, and lignin indicated nonsignificant terms for crude protein, ether extract, and lignin. A second regression related methane production to the remaining terms (R^2 = .67, $S_{y.x}$ = .62):

$$CH_4\text{(Mcal/day)} = .814 + .122 \pm .018 \text{ soluble residue (kg fed)} + .415 \pm .074 \text{ hemicellulose (kg fed)} + .633 \pm .076 \text{ cellulose (kg fed)}$$

Total methane production also was related to the amount of each carbohydrate component that apparently was digested as (R^2 = .73, $S_{y.x}$ = .56):

$$CH_4\text{(Mcal/day)} = .439 + .273 \pm .015 \text{ soluble residue (kg digested)} + .512 \pm .078 \text{ hemicellulose (kg digested)} + 1.393 \pm .097 \text{ cellulose (kg digested)}$$

Production of methane per gram of cellulose digested is nearly three times that per gram of hemicellulose digested and five times that per gram of soluble residue digested. A part of the latter difference may be due to a substantially lower proportion of soluble residue's being fermented in the rumen and a larger proportion being digested and absorbed as glucose in the small intestine. A substantial amount of hemicellulose also may escape fermentation in the rumen. The production of methane from 26 soluble carbohydrates was studied by Czerkawski and Breckenridge (4) in 53 experiments with an artificial rumen. They concluded that, with the exception of rhamnose, the amount of methane produced was not dependent on the type of carbohydrate but rather the amount of carbohydrate fermented. The mean amount of methane produced was 6 kcal/100 kcal of sugar fermented. If the gross energy value of carbohydrate apparently digested in our experiment is 4.2 kcal/g, the

TABLE 1. Mean and range of diet composition, intakes, and methane production.

Variable	Units	Mean	SD	Minimum	Maximum
Body weight	kg	617	101	369	893
Dry matter	kg/day	12.13	4.28	2.72	22.93
Crude protein	%	15.15	2.53	4.92	23.26
Ether extract	%	2.57	.63	.90	5.10
Soluble residue	%	41.08	7.09	18.08	54.10
Hemicellulose	%	15.13	3.73	7.07	28.17
Cellulose	%	14.31	4.00	8.53	34.25
Lignin	%	5.08	1.51	2.16	13.69
Protein	kg/day	1.84	.73	.27	3.83
Soluble residue	kg/day	5.06	2.10	.95	9.66
Hemicellulose	kg/day	1.80	.72	.47	4.41
Cellulose	kg/day	1.71	.68	.41	3.90
Digestible soluble residue	kg/day	4.64	1.91	.86	9.26
Digestible hemicellulose	kg/day	.86	.43	.01	2.81
Digestible cellulose	kg/day	.80	.36	.21	1.94
Methane production	Mcal/day	3.27	1.07	.91	5.81
Methane production	% of GE	6.31	1.46	1.60	9.90

TABLE 2. Effect of intake on methane production from digestible carbohydrate fractions.

Intake (X maintenance)	N	SD	R^2	Intercept	Mcal CH_4 produced/kg carbohydrate digested					
					Soluble residue		Hemicellulose		Cellulose	
					b	SE_b	b	SE_b	b	SE_b
<1.5	103	.29	.66	.462	.460	.040	.538	.121	.634	.107
1.5 – 2.5	119	.48	.65	.227	.285	.047	.630	.153	1.521	.162
2.5 – 3.5	152	.62	.61	−.569	.355	.047	.515	.131	1.957	.170
>3.5	30	.81	.53	−.502	.360	.154	.610	.421	1.372	.581
Intake >1.5	301	.60	.65	.322	.255	.023	.451	.093	1.699	.119
All data	404	.56	.73	.438	.273	.015	.512	.078	1.393	.097

kcal methane produced/100 kcal of carbohydrate apparently digested was 6.5 for soluble residue, 11.5 for hemicellulose, and 33.6 for cellulose. Our data indicate major differences in the amount of methane produced during the digestion of various carbohydrate fractions. Experiments of the type described by Czerkawski and Breckenridge (4) are needed to establish relationships between fermentation of structural carbohydrates and methane production.

The effect of intake on methane production was studied by deriving separate regressions within four classes of intake. These data are in Table 2. Methane production was not influenced as much by type of carbohydrate digested at low intake as at higher intakes. The differences among the partial regression coefficients for individual digestible carbohydrate fractions were less at intakes of less than 1.5 times maintenance than at higher intakes. Much of this difference is associated with the digestible cellulose fraction that increased from .634 Mcal CH_4/kg below 1.5 times maintenance to 1.699 Mcal CH_4/kg above 1.5 times maintenance. The latter rate of methane production is equivalent to 41% of the cellulose energy apparently digested. Likely, the high rate of methane production associated with cellulose degradation indicates a partial shift from a propionate type fermentation to methanogenic fermentation in the rumen. The magnitude of methane production associated with cellulose digestion, however, suggests that methane would have to come from sources other than the products of cellulose degradation alone to balance the stoicheometry of the conversion of cellulose to end-products of fatty acids and gases.

Production of methane is influenced by the nature of the carbohydrate digested, but this effect is relatively less important at low than at high feed intake. In efforts to test this observation more directly, regressions were derived for the data within several intakes; the intake of

TABLE 3. Effect of intake on error in prediction of methane production.

Intake (X maintenance)	N	Independent variable in prediction					
		Dry matter intake (kg/day)		Digestible carbohydrate (kg/day)		Digestible soluble residue, digestible hemicellulose, and digestible cellulose (kg/day)	
		$S_{y.x}$	R^2	$S_{y.x}$	R^2	$S_{y.x}$	R^2
<1.5	103	.30	.64	.30	.65	.29	.66
1.5 – 2.5	119	.62	.40	.64	.36	.48	.65
2.5 – 3.5	152	.80	.34	.84	.27	.62	.61
>3.5	30	.87	.40	.89	.37	.81	.53
>1.5	301	.75	.44	.78	.40	.60	.65

dry matter, total digestible carbohydrate, and individual carbohydrate components were independent variables. The standard errors and R^2's are in Table 3. At intakes below 1.5 times maintenance, methane production is nearly as related to either dry matter intake or total digestible carbohydrate alone as to individual digestible carbohydrate components (R^2 = .64, .65, and .66). At intakes above 1.5 times maintenance, however, consideration of the individual amounts of soluble residue, hemicellulose, and cellulose apparently digested provided a substantial improvement in the precision with which methane production was predicted (R^2 = .65 vs. .44 and .40) as compared to either dry matter or total carbohydrate digested.

Separate regressions were obtained for diets based on corn silage and those containing hay. No differences were apparent, and we conclude that the carbohydrate components of these forage classes influence methane production similarly.

We conclude that whereas the methane production by adult cattle at maintenance can be predicted adequately from dry matter or total digestible carbohydrate, accurate prediction of methane production by lactating dairy cattle requires determination of the nature of the carbohydrate as well.

REFERENCES

1 Blaxter, K. L., and J. L. Clapperton. 1965. Prediction of the amount of methane produced by ruminants. Brit. J. Nutr. 19:511.

2 Bratzler, J. W., and E. B. Forbes. 1940. The estimation of methane production by cattle. J. Nutr. 19:611.

3 Brouwer, E. 1965. Report of sub-committee on constants and factors. Proc. 3rd Sympos. on Energy Metabolism, Troon, Scotland, Europ. Ass. Anim. Prod. Publ. No. 11:441.

4 Czerkawski, J. W., and G. Breckenridge. 1969. Fermentation of various soluble carbohydrates by rumen micro-organisms with particular reference to methane production. Brit. J. Nutr. 23:925.

5 Goering, H. K., and P. J. Van Soest. 1970. Forage fiber analysis: apparatus, reagents, procedures and some applications.

6 Harvey, W. R. 1975. Least squares analysis of data with unequal subclass numbers. USDA ARS-H-4.

7 Kriss, M. 1930. 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. Agr. Res. 40:283.

8 Moe, P. W., and H. F. Tyrrell. 1972. The net energy value for lactation of high- and low-protein diets containing corn silage. J. Dairy Sci. 55:318.

9 Moe, P. W., and H. F. Tyrrell. 1977. Effects of feed intake and physical form on energy value of corn in timothy hay diets for lactating cows. J. Dairy Sci. 60:752.

10 Moe, P. W., and H. F. Tyrrell. 1977. The incremental energy value of wheat bran for dairy cows. Northeastern Section ADSA-ASAS Mtgs. (Abstr.)

11 Moe, P. W., and H. F. Tyrrell. 1979. Effect of endosperm type on incremental energy value of corn grain for dairy cattle. J. Dairy Sci. 62:447.

12 Moe, P. W., H. F. Tyrrell, and N. W. Hooven, Jr. 1973. Energy balance measurements with corn meal and ground oats for lactating cows. J. Dairy Sci. 56:1149.

13 Moe, P. W., H. F. Tyrrell, and N. W. Hooven, Jr. 1973. Physical form and energy value of corn grain. J. Dairy Sci. 56:1298.

14 Swift, R. W., J. W. Bratzler, W. H. James, A. D. Tillman, and D. C. Meek. 1948. The effect of dietary fat on utilization of the energy and protein of rations by sheep. J. Anim. Sci. 7:475.

15 Tyrrell, H. F., and P. W. Moe. 1972. Net energy value for lactation of a high and low concentrate ration containing corn silage. J. Dairy Sci. 55:1106.

16 Tyrrell, H. F., P. W. Moe, and L. S. Bull. 1973. Energy value of cracked corn and dried beet pulp fed to Holstein cows. J. Dairy Sci. 56:1384 (Abstr.)

17 Tyrrell, H. F., and P. W. Moe. 1974. Net energy value for lactation of a corn and a barley ration. J. Dairy Sci. 57:451.

18 Tyrrell, H. F., and P. W. Moe. 1979. Unpublished data.