

Impact of pasture type on methane production by lactating beef cows

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McCaughey, W. P., Wittenberg, K. and Corrigan, D. 1999. **Impact of pasture type on methane production by lactating beef cows.** *Can. J. Anim. Sci.* **79**: 221–226. In order to determine the quantity of methane (CH₄) produced by lactating beef cows on pasture, 16 Hereford–Simmental first-calf heifers with a mean weight of 511.2 ± 5.8 kg were randomly selected from a larger group of cows (*n* = 60) on a grazing management experiment and used to evaluate the effects of pasture type on ruminal CH₄ production using the sulfur hexafluoride (SF₆) tracer-gas technique. Pasture treatments consisted of two pasture types, alfalfa-grass [78% alfalfa (*Medicago sativa* L.) – 22% meadow bromegrass (*Bromus biebersteinii* Roem and Schult.)] or 100% meadow bromegrass at each of two fertility levels (either unfertilized or soil test recommended fertilizer levels) with two replications of each pasture treatment (8 pastures). Cows were managed using a “put and take” stocking system to leave equal residual herbage mass on all treatments following the grazing period in each paddock. During the 69-d grazing season, two cows from each pasture were sampled to determine daily forage intake and CH₄ production on four occasions. The chemical composition of diets differed between pasture types and sampling periods. Dry matter intake was greater for cows grazing alfalfa–grass pastures than for cows grazing grass-only pastures (11.4 vs. 9.7 kg DM d⁻¹; *P* < 0.018). However, methane production was greater for cows grazing alfalfa–grass pastures than for cows grazing grass-only pastures (373.8 vs. 411.0 L CH₄ d⁻¹; *P* < 0.008). Consequently, energy lost through eructation of CH₄ was less for cows grazing alfalfa–grass pastures than it was for cows grazing grass-only pastures (7.1 vs. 9.5% of GEI; *P* < 0.001).

Key words: Methane, cattle, environment, digestion efficiency, pasture, forage

McCaughey, W. P., Wittenberg, K. et Corrigan, D. 1999. **Incidence de la composition botanique du pâturage sur la production de méthane par les vaches d'élevage de boucherie en lactation.** *Can. J. Anim. Sci.* **79**: 221–226. Seize génisses croisées Hereford–Simmental primipares en lactation, pesant en moyenne 511,2 ± 5,8 kg, ont été prises au hasard dans une plus grande population de vaches (*n* = 60) pour participer à une expérience de conduite du pâturage. L'objet était d'évaluer les effets de la composition du pâturage sur la production ruminale de CH₄ au moyen de la technique au gaz traceur hexafluorure de soufre (SF₆). Deux types de pâturage étaient comparés, 1 peuplement pur de brome des prés (*Bromus biebersteinii* Roem & Schult.) et un mélange à 78 % luzerne (*Medicago sativa* L.) et 22 % brome des prés, chacun à deux niveaux de fertilité, sans fumure et fumure recommandée selon l'analyse du sol. Chaque traitement comportait 2 répétitions. Le chargement animal adopté était du type variable, de façon à laisser une même masse herbagère résiduelle dans tous les traitements au terme de la période de pâturage. Durant cette période de 79 jours, deux vaches de chaque enclos étaient utilisées à 4 reprises pour déterminer l'ingestion quotidienne d'herbe et la production de CH₄. La composition chimique du fourrage différait selon la nature du pâturage et selon la date des prélèvements. L'ingéré de m.s. était plus abondant chez les vaches pâturant l'association luzerne-graminée que chez celles broutant le peuplement pur de graminée (11,4 contre 9,7 kg m.s. j⁻¹; *P* < 0,018). En revanche c'est l'inverse que l'on observait pour la production de méthane (373,8 contre 411,0 L CH₄ j⁻¹; *P* < 0,008). Par conséquent, les déperditions d'énergie par éructation du CH₄ étaient moins importantes chez les vaches pâturant l'association luzerne-graminée que chez celles pâturant la graminée en peuplement pur soit 7,1 contre 9,5 % de l'ingéré énergétique brut (IEB) (*P* < 0,001).

Mots clés: Méthane, bovin, environnement, digestibilité, pâturage, fourrage

The dietary, environmental and microbiological aspects of CH₄ production in ruminants have been recently reviewed (Johnson and Johnson 1995; McAllister et al. 1996). However, these extensive reviews contain no information on methane production by free-ranging cattle. McCaughey et al. (1997) recently used the SF₆ tracer gas technique (Johnson et al. 1994a) to measure the impact of grazing management on methane production by steers on pasture.

The production of CH₄ by cattle and other ruminants has become a subject of scientific debate as awareness and concern over global warming increase. Domestic animals (primarily cattle) may be responsible for as much as 15% of the

world's output of CH₄ (Crutzen et al. 1986) and, therefore, may be considered significant contributors to the greenhouse effect. At the present time, CO₂ is considered to be the most important greenhouse gas (Pearce 1989). However, atmospheric CH₄ concentrations are increasing rapidly. This

Abbreviations: ADF, acid detergent fiber; ADG, average daily gain; CP, crude protein; CRC, controlled release capsule; DMI, dry matter intake; GE, gross energy; GEI, gross energy intake; IVOMD, in vitro organic matter digestibility; NDF, neutral detergent fiber; OMI, organic matter intake, SF₆, sulfur hexafluoride.

is causing concern since CH_4 is more efficient in trapping heat than CO_2 . In time, it is possible that CH_4 may become the dominant greenhouse gas (Cicerone and Oremland 1988; Pearce 1989).

Methane production by ruminant animals results from the fermentation of feedstuffs in the gastrointestinal tract and represents a loss of dietary energy. Most studies have measured CH_4 gas production using respiration chambers in which animals are fed conserved, and often processed, forages (Blaxter and Clapperton 1965). The majority of work in this field has been conducted on dairy cattle fed primarily high-energy rations (Holter and Young 1992). In contrast to dairy cattle, most beef cattle are kept on pasture for 5 to 12 mo each year, depending on geographic location. Differences between confined, chamber-fed animals consuming conserved feedstuffs and grazing animals, in terms of feeding behavior and rumen digestion kinetics, may be expected as animals on pasture may have higher voluntary intake and rate of passage than chamber-fed animals because they frequently consume less-mature feedstuffs. Pastured animals may also graze for extended periods of time, which may total as much as 8–12 h per day (Popp et al. 1997).

Johnson et al. (1994a) described a technique for measuring CH_4 production by cattle using an inert tracer gas source placed in the rumen of the animal. The use of the SF_6 tracer gas technique has made it possible to obtain reliable estimates of ruminal methane production by individual cattle. Although there do not appear to be any publications reporting the quantity of methane lost via the rectum in cattle, some information does exist for sheep. Murray et al. (1976) reported that 87% of total methane production was produced in the rumen with 13% in the lower digestive tract. Of the methane produced in the lower digestive tract, approximately 89% was reabsorbed into the blood stream and expired through the lungs. This indicates that as much as 98% of the total methane produced by sheep may be expired through the mouth and nose. Also, indirect evidence comparing methane production by cattle in chambers with values using the SF_6 technique suggest that the SF_6 technique accounts for approximately 93% of the total methane produced by cattle (Johnson et al. 1974b). These results suggest that the SF_6 technique may account for 93–98% of total methane production. Currently, no published information exists documenting CH_4 production by lactating beef cows under range or pasture conditions. The objective of this experiment was to quantify CH_4 production by lactating beef cows grazing alfalfa–grass and grass–only pastures.

MATERIALS AND METHODS

During the 1994 grazing season, 16 Hereford–Simmental first-calf heifers in early lactation averaging 511.2 ± 8.2 kg were randomly selected from a larger group of 60 similar animals for determination of CH_4 production during the grazing season. The experiment was conducted on eight, 3.7-ha pastures being used in an experiment to examine the effects of pasture type and soil fertility on beef cow–calf production. The four legume–grass pastures were of similar botanical composition (78% by mass alfalfa [*Medicago sati-*

va L.] – 22% meadow brome [*Bromus biebersteinii* Roem and Schult.]) and the four grass pastures consisted of 100% meadow brome grass. The experimental treatments consisted of four combinations of the two pasture types and two fertility levels with two replications of each pasture treatment.

The first two sampling dates occurred during the first grazing rotation when cows entered (11 July) and exited (20 July) the third paddock in a five-paddock rotation and the last two sampling dates occurred when cows entered (9 August) and exited (15 August) the third paddock during the second five-paddock rotation. The third paddock was selected for sampling because it was approximately half-way through each of the two rotations and would give the best approximation of average forage quality in each rotation. The experimental protocol was reviewed by the Brandon Research Centre Animal Care Committee to ensure that animals used in this study were cared for in accordance with the principles outlined by the Canadian Council on Animal Care.

In addition to the 16 cows being used to measure methane, four esophageally fistulated steers were kept on pastures of similar botanical composition to the treatment pastures and used to monitor the quality of ingested herbage. On each sampling date, one esophageally fistulated steer fitted with a canvas collection bag was used to obtain diet quality samples from each experimental pasture. The fistulated steers were fasted overnight prior to being used to sample each pasture treatment. Four of the pastures were sampled in the morning and four were sampled in the afternoon. The fistulated steers were kept in the treatment pastures for 20 to 40 min to collect sufficient plant material for chemical analysis following the protocol of Cohen (1979). Extrusa samples were squeezed through two layers of cheesecloth and saliva fractions were collected and used to correct analyses for organic matter losses (Cohen 1979). Squeezed samples were dried in a forced-draught oven at 50°C for at least 48 h and ground using a Wiley mill fitted with a 1-mm screen. Dried samples were analyzed for CP (Association of Official Analytical Chemists [AOAC] 1984, method 7.025), ADF, NDF (Goering and Van Soest 1970), and ash (AOAC 1984, method no. 7.009). Gross energy was determined using a Parr adiabatic bomb calorimeter (model 1241). In vitro organic matter digestibility was determined by a modification (Troelsen and Hanel 1966) of the method of Tilley and Terry (1963) using bovine instead of ovine inoculum.

Voluntary intake was determined using chromium sesquioxide (Cr_2O_3) controlled-release capsules (Captechrome, Nufarm Ltd., New Zealand) to estimate fecal output (Barlow et al. 1988). The IVOMD values of pasture samples were used to predict voluntary intake of digestible organic matter. To allow for the lag times associated with passage of feed through the digestive tract and to ensure that intake estimates approximately corresponded to the CH_4 collection periods, fecal samples were taken 48 h after paddock entry and 12 h after paddock exit.

Methane gas production was determined by the SF_6 tracer gas method (Johnson et al. 1994). Using this method, permeation tubes (12.5 mm \times 40 mm) containing SF_6 with a pre-determined release rate were placed in the rumen. The

Table 1. Analysis of variance for diet quality factors (DM basis)

Parameters	F	P	F×P	r ²	CV	Std. dev.	Mean
CP (%)	***	***	***	0.86	14.4	1.6	11.1
IVOMD (%)	***	***	***	0.86	4.7	2.3	48.1
ADF (%)	**	***	***	0.84	6.2	2.7	44.3
NDF (%)	***	***	***	0.88	6.9	4.5	65.8
Ash (%)	NS	***	NS	0.73	9.3	0.9	10.2
GE (Mcal kg ⁻¹)	NS	**	NS	0.58	1.3	0.1	4.4

F= pasture type; P= sampling period.

*, **, *** $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; NS, not significant.

rate of SF₆ release from a permeation tube was determined by measuring the weight loss of the permeation tube over a set period of time during which the permeation tube was incubated at 39°C. Release rates of the permeation tubes used in this study ranged from 356 to 1276 ng min⁻¹. Expired gases were sampled using a gas collection apparatus fitted to a halter and suspended from the neck of the animal (McCaughey et al. 1997). This apparatus consisted of a 130-mm-diameter stainless steel sphere evacuated to approximately 30 mm Hg. The sphere was suspended by a strap from the neck of the animal and was attached to a halter fitted with an air-tight connection to a 900-mm length of restriction tubing (128 µm i.d.) with an in-line 15-µm filter and flexible nose piece. Gas collection spheres were changed approximately every 24 h. Based on preliminary research, expired gases were sampled in a linear manner over a 24-h period. Prior to gas sampling, the animals were allowed to adapt to wearing a dummy gas collection apparatus for 7 d. No effect was observed in grazing behaviour once the test animal was adapted to the apparatus.

Following the removal of the gas collection spheres from the cows, they were pressurized to 110 KPa with pure N₂ and taken to the laboratory for further analysis. The pressurization was to prevent sample contamination prior to gas analysis and to allow injection of a gas sample into the sample loop of a gas chromatograph. A gas chromatograph (Star 3400, Varian, Mississauga, ON) fitted with electron capture and flame ionization detectors was used for determination of SF₆ and CH₄, respectively. The samples were run on the gas chromatograph using a Molecular Sieve 0.5 nm (1800 mm) column and a Poropak QS (1800 mm) column for SF₆ and CH₄, respectively. The temperature of the column oven was 35°C and nitrogen was used as the carrier gas with a flow rate of 30 mL min⁻¹. Prepared standards were used to standardize the gas chromatograph for both SF₆ (Scott-Marrin Inc., Riverside, CA) and CH₄ (Supelco, Mississauga, ON) prior to sample analysis. Methane production was determined using the formula developed by Johnson et al. (1994a):

$$\text{CH}_4 \text{ production (ng min}^{-1}\text{)} = \text{Perm. tube SF}_6 \text{ release rate (ng min}^{-1}\text{)} \times [\text{CH}_4]/[\text{SF}_6]$$

The experiment was analyzed using a split-plot design with the main plots arranged in a completely randomized design. The analysis was performed using the GLM procedure of the SAS Institute, Inc. (1985). The main plot treatments were the pasture type and fertility and sub-plots were sam-

pling dates. However, after fertility was shown to have no effect on methane production it was removed from the model. The statistical model used was:

$$Y_{ijk} = F_i + R_j + (FR)_{ij} + P_k + (FP)_{ik} + e_{ijk}$$

where Y_{ijk} = methane production of the ijk th cow, F_i = i th pasture type, R_j = j th replication, P_k = k th sampling period and e_{ijk} = the experimental error term. Pasture type (F_i) was tested against the error A term ($(FR)_{ij}$) and period (P_k) and pasture type by period interaction ($(FP)_{ik}$) effects were tested against the experimental error term (e_{ijk}). When the error A term was found not to differ from the experimental error term, the error terms were pooled for the final analysis.

RESULTS

Diet Quality

Both pasture type and sampling period had significant effects ($P < 0.05$) on the nutritive value of forage (Table 1). Interactions between grazing treatment and sampling period were significant for CP, IVOMD, ADF and NDF (Tables 1 and 2). Ash and gross energy content (Tables 1 and 2) of the pasture did not differ between pasture types but did vary between sampling periods.

Voluntary Intake and CH₄ Production

Cow weight did not differ significantly between pasture types or sampling dates and averaged 511.2 ± 5.2 kg. Pasture type affected voluntary intake measurements and methane production as a percentage of GEI, while both pasture type and sampling date affected CH₄ production when measured as L d⁻¹, L kg BW⁻¹ d⁻¹, or L kg BW^{-0.75} d⁻¹ (Table 3). Cows on alfalfa-grass pastures had a higher voluntary intake than cows on grass-only pastures when measured as DMI (11.4 vs. 9.7 kg d⁻¹; $P < 0.018$), OMI (10.3 vs. 8.7 kg d⁻¹; $P < 0.013$) and GEI (49.8 vs. 42.6 Mcal d⁻¹; $P < 0.021$) (Table 4). Methane production was lower on alfalfa-grass pastures than on grass-only pastures (373.8 vs. 411.0 L d⁻¹; $P < 0.008$). A similar result was obtained when the results were calculated on a kilogram of body weight basis (0.74 vs. 0.81 L kg BW⁻¹ d⁻¹; $P < 0.012$) and on the basis of metabolic body weight (3.49 vs. 3.83 L kg BW^{-0.75} d⁻¹; $P < 0.009$). When the energy lost through eructation of methane was expressed as a percentage of gross energy intake, cows grazing alfalfa-grass pastures lost less energy than cows grazing grass-only pastures (7.1 vs. 9.5% of GEI; $P < 0.001$).

Table 2. Effect of pasture type and stage of season on chemical composition (DM basis) of esophageal extrusa samples from lactating beef cows

Parameter	Period	Pasture type		SEM	P-value
		Alfalfa-grass	Grass-only		
CP (%)	11 July	17.1A	8.5B	0.5	0.001
	20 July	9.9B	6.0C	0.3	0.002
	9 August	15.1A	11.1A	0.7	0.040
	15 August	10.5B	10.6A	0.6	NS
	SEM	0.5	0.3		
	P-value	0.001	0.001		
	Avg.	13.1	9.0	0.3	0.001
IVOMD (%)	11 July	56.2A	42.9B	0.9	0.001
	20 July	48.3B	42.0B	0.6	0.003
	9 August	53.7A	47.5A	0.8	0.012
	15 August	46.7B	47.4A	0.7	NS
	SEM	0.7	0.4		
	P-value	0.002	0.001		
	Avg.	51.2	45.0	0.4	0.001
ADF (%)	11 July	34.5B	46.4B	1.0	0.002
	20 July	50.4A	49.7A	1.0	NS
	9 August	38.3B	43.4B	1.0	0.056
	15 August	48.0A	43.9B	0.9	0.070
	SEM	0.9	0.4		
	P-value	0.001	0.001		
	Avg.	42.8	45.9	0.5	0.005
NDF (%)	11 July	44.7C	73.5AB	1.7	0.001
	20 July	67.2A	78.4A	1.7	0.020
	9 August	53.1B	69.4B	1.4	0.002
	15 August	68.6A	71.1AB	1.1	NS
	SEM	1.3	1.0		
	P-value	0.001	0.044		
	Avg.	58.4	73.1	0.8	0.001
Ash (%)	11 July	10.1AB	9.5B	0.3	NS
	20 July	8.8B	8.5B	0.3	NS
	9 August	10.9A	11.4A	0.2	NS
	15 August	10.2AB	12.1A	0.5	NS
	SEM	0.2	0.3		
	P-value	0.043	0.001		
	Avg.	10.0	10.4	0.2	NS
GE (Mcal kg ⁻¹)	11 July	4.41	4.33B	0.01	0.028
	20 July	4.29	4.30B	0.02	NS
	9 August	4.37	4.46A	0.02	0.087
	15 August	4.33	4.38AB	0.03	NS
	SEM	0.01	0.02		
	P-value	NS	0.021		
	Avg.	4.35	4.36	0.01	NS

A–C Variable values within each pasture type followed by different letters are significantly different ($P < 0.05$) using Student–Newman–Keul's test. NS, not significant.

DISCUSSION

The diet quality of cows grazing either alfalfa-grass or grass-only pasture changed dramatically during the grazing season. These differences primarily occurred between paddock entry and paddock exit for each pasture type. This resulted in the complex pattern of interactions seen in Table 2. Thus, the experiment was successful in creating a wide range in diet quality.

The observations of higher voluntary intake on alfalfa–grass pastures compared with grass-only pastures is

not surprising. Higher voluntary intakes have been frequently obtained on legume-based pastures compared with grass-based pastures as digestibility and rate of passage are greater for legumes than grasses (Minson and Wilson 1994).

Under tightly controlled experimental conditions in respiration chambers, Blaxter and Clapperton (1965) observed that both feed intake and digestibility were important factors affecting CH₄ production. In contrast, cattle on pasture have the opportunity to graze selectively and there is likely to be more variability associated with the measurement of volun-

Table 3. Analysis of variance for voluntary intake and methane production by lactating beef cows

Parameter	F	P	F×P	r ²	CV	Std. dev.	Mean
Wt. (kg)	NS	NS	NS	0.13	6.4	32.7	511.2
DM Intake (kg d ⁻¹)	**	NS	NS	0.31	23.1	2.4	10.5
OM Intake (kg d ⁻¹)	**	NS	NS	0.31	22.9	2.2	9.4
GE Intake (Mcal d ⁻¹)	*	NS	NS	0.31	23.0	10.5	45.8
Methane (L d ⁻¹)	**	*	***	0.63	14.5	57.1	391.4
Methane (L kg BW ⁻¹ d ⁻¹)	*	**	***	0.59	14.9	0.11	0.76
Methane (L kg BW ^{-0.75} d ⁻¹)	***	**	***	0.61	14.6	0.53	3.65
Methane (% of GEI)	***	NS	NS	0.55	24.2	2.03	8.40

F= Pasture type; P= sampling period.

*, **, *** $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; NS, not significant.

Table 4. Effect of pasture type and sampling date on intake and methane production by lactating beef cows

Parameter	Period	Pasture type		SEM	P-value
		Alfalfa-grass	Grass-only		
Weight (kg)	Avg.	506.2	516.2	5.8	NS
DM Intake (kg d ⁻¹)	Avg.	11.4	9.7	0.4	0.018
OM Intake (kg d ⁻¹)	Avg.	10.3	8.7	0.4	0.013
GE Intake (Mcal d ⁻¹)	Avg.	49.8	42.6	1.9	0.021
Methane (L d ⁻¹)	11 July	440.4A	365.8	20.3	0.044
	20 July	364.5B	455.0	16.5	0.007
	9 August	419.5AB	405.3	22.4	NS
	15 August	269.6C	425.0	20.7	0.001
	SEM	15.0	13.4		
	P-value	0.001	NS		
	Avg.	373.8	411.0	10.1	0.008
Methane (L kg BW ⁻¹ d ⁻¹)	11 July	0.87A	0.72	0.04	0.036
	20 July	0.72B	0.92	0.04	0.008
	9 August	0.81AB	0.79	0.04	NS
	15 August	0.54C	0.81	0.04	0.001
	SEM	0.02	0.03		
	P-value	0.001	NS		
	Avg.	0.74	0.81	0.02	0.012
Methane (L kg BW ^{-0.75} d ⁻¹)	11 July	4.12A	3.40	0.19	0.035
	20 July	3.39B	4.34	0.17	0.008
	9 August	3.86AB	3.78	0.20	NS
	15 August	2.58C	3.87	0.19	0.001
	SEM	0.12	0.15		
	P-value	0.001	NS		
	Avg.	3.49	3.83	0.09	0.009
Methane (% of GEI)	Avg.	7.1	9.5	0.4	0.001

A–C Variable values within each pasture type followed by different letters are significantly different ($P < 0.05$) using Student–Newman–Keul's test. NS, not significant.

tary intake and diet quality than is the case for chamber-fed animals. As a result, despite observing a wide range in diet quality, and observing differences in voluntary intake and methane production due to pasture type, it was not possible to develop generalized equations for predicting methane production based on these variables.

Voluntary intake was observed to differ between pasture types, but not between sampling periods. Methane production, however, did vary between sampling periods. This is likely primarily due to changes in forage quality during the period of occupation of a paddock, but may also result from day to day variation in methane production. Overall, the

energy lost through eructation of CH₄ averaged approximately 7.1 and 9.5 ± 0.4% for alfalfa-grass and grass-only pastures, respectively, which is within the range of values reported for forage-fed dairy cows and heifers (Holter and Young 1992). However, no direct measurements of CH₄ production by free-ranging lactating beef cows are available for comparison.

The results obtained in this study indicate that improving pasture quality through addition of legumes such as alfalfa to the pasture mix may potentially reduce methane production by close to 10%. Further gains in the efficiency of beef production per unit of methane produced may result due to

the greater calf growth rates (+11%), which were also observed on the alfalfa-grass pastures used in this study.

The SF₆ technique used in this study allowed direct estimates of ruminal CH₄ production to be made in free-ranging cattle, but the technique did not allow quantification of CH₄ produced in the hindgut and lost via the rectum. Therefore, to estimate total methane produced by the animal, values will need to be adjusted upward to account for the proportion of CH₄ lost via the rectum. The data of Murray et al. (1976) and Johnson et al. (1994b) indicate that this adjustment might increase methane production values by 2–7% for sheep and cattle, respectively. Unfortunately, there are no direct estimates of hindgut CH₄ production in the literature for cattle and this is an area that requires urgent research attention.

ACKNOWLEDGEMENTS

The technical assistance of Clayton Robins, Juanita Kopp and Jim McGhee is gratefully acknowledged. This work was funded by Agriculture and Agri-Food Canada's Greenhouse Gas Initiative.

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