Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride (SF_6) tracer gas technique

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Boadi, D. A. and Wittenberg, K. M. 2002. **Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride (SF_6) tracer gas technique**. Can. J. Anim. Sci. **82**: 201–206. The effects of cattle breed type [dairy (Holstein) versus beef (Charolais × Simmental)] and forage quality (high, medium and low) on methane production were measured under ad-libitum and restricted feeding conditions. The in vitro organic matter digestibility (IVOMD) of the forage diets was high = 61.5%, medium = 50.7% and low = 38.5%. Each hay diet was fed to four animals (two dairy and two beef heifers) in three periods of four 3 × 3 Latin squares. Each period consisted of 23 d during which heifers were individually fed their assigned forage for 14 d on ad-libitum feeding. Following this, intake was restricted to 2% of body weight (BW) for 9 d. Methane production was measured for five 24-h intervals in each period at both levels of intake using the SF_6 gas technique. Methane production was not different ($P > 0.05$) between dairy (238.0 ± 6.9 L d^{-1}) and beef cattle (228.6 ± 7.8 L d^{-1}) under either level of feeding. Forage quality affected CH_4 (L d^{-1}) output, with high = medium > low during ad-libitum feeding. This effect of forage quality on CH_4 production was absent during restricted feeding ($P > 0.05$). Day-to-day variation in CH_4 production was 26.9 and 27.1% on ad-libitum and restricted feeding respectively ($P < 0.05$), whereas animal-to-animal variation ($P < 0.05$) was 26.6% (ad libitum) and 25.3% (restricted). On ad-libitum feeding, dry matter intake (DMI) was strongly correlated ($P = 0.0001$; $r = 0.8$) with CH_4 production (L d^{-1}), and accounted for 64% of daily variation in CH_4 production. Methane [L kg^{-1} digestible organic matter intake (DOMI)] was highest ($P < 0.05$) on low-quality diets under both feeding regimes, and was not influenced ($P > 0.05$) by cattle type. Methane production as a percent of gross energy intake (GEI) was not influenced by diet. It can be concluded that the SF_6 tracer technique provides a measure of enteric CH_4 production directly from animals under production conditions. There were no differences in CH_4 production between dairy and beef breeds, but the quality of forages affected CH_4 production under both ad-libitum and restricted feeding.

Key words: Methane, SF_6 tracer technique, cattle breed type, forage quality, level of intake

Boadi, D. A. et Wittenberg, K. M. 2002. **Dosage du méthane libéré par les génisses à lait et à viande nourries de fourrage à concentration variable en éléments nutritifs par traçage à l'hexafluorure de soufre (SF_6)**. Can. J. Anim. Sci. **82**: 201–206. Les auteurs ont mesuré l'incidence du type de bovin [race laitière (Holstein) ou de boucherie (Charolais × Simmental)]et de la qualité du fourrage (haute, moyenne, faible) sur le volume de méthane produit par des génisses nourries à satiété ou rationnées. La digestibilité *in vitro* de la matière sèche organique correspondait à 61,5 % pour le fourrage de haute qualité, à 50,7 % pour celui de qualité moyenne et à 38,5 % pour celui de faible qualité. Chaque type de fourrage a été servi à quatre animaux (2 génisses laitières et 2 de boucherie) trois périodes durant, en quatre carrés latins 3 × 3. Chaque période comportait 23 jours durant lesquels les animaux ont chacun reçu le type de fourrage qui leur avait été attribué à satiété pendant 14 jours et à raison de 2 % du poids corporel les 9 jours suivants. La production de méthane ne varie pas ($P <$,05) entre les bovins laitiers (238,0 ± 6,9 litres par jour) et les animaux de boucherie (228,6 ± 7,8 litres par jour) aux deux taux d'engrais. La qualité du fourrage agit sur la production de CH_4 (litres par jour) dans l'ordre élevée = moyenne > faible quand les animaux sont nourris à satiété, mais pas quand il y a rationnement ($P >$ 0,05). Le volume de CH_4 varie quotidiennement de 26,9 % et de 27,1 % quand les animaux sont nourris à satiété ou rationnés, respectivement ($P <$ 0,05), tandis que la variation d'un animal à l'autre ($P <$ 0,05) s'élève à 26,6 % (à satiété) et à 25,3 % (rationné). Quand les animaux sont nourris à satiété, l'absorption de matière sèche présente une forte corrélation (P = 0,0001; r = 0,8) avec la production de CH_4 (litres par jour) et explique 64 % de la variation du volume de gaz produit quotidiennement. La libération de méthane (litres par kg de matière organique digestible absorbée) est la plus forte ($P <$ 0,05) avec le fourrage de faible qualité, quel que soit le régime, et ne varie pas avec le type d'animal. Quand elle est exprimée en pourcentage de l'absorption d'énergie brute, la production de méthane ne varie pas avec le régime. On en conclut que la technique de traçage au SF_6 permet de mesurer directement la production entérique de CH_4 des animaux, dans les conditions normales d'élevage. Le volume de CH_4 libéré ne varie pas avec le type d'animal, mais bien avec la qualité du fourrage, quand il est servi à satiété ou est rationné.

Mots clés: Méthane, SF_6, traçage au gaz, type de bovin, qualité du fourrage, taux d'absorption

Abbreviations: **ADF**, acid detergent fibre; **BW**, body weight; **CP**, crude protein; **DM**, dry matter; **DMI**, dry matter intake; **DOMI**, digestible organic matter intake; **GEI**, gross energy intake; **IVOMD**, in vitro organic matter digestibility; **NDF**, neutral detergent fibre

Methane production resulting from fermentation of feed in the gastrointestinal tract of ruminants represents a loss of dietary energy that is typically about 2–12% of GEI (Johnson and Johnson 1995). Methane production primarily depends on the quantity and quality of the feed that affects rate of digestion and rate of passage in the fermentation process (Van Soest 1982). Several other factors such as body size, gastrointestinal capacity, animal species, breed and environmental conditions can also influence the amount of CH_4 produced (McAllister et al. 1996); however, the exact interrelationships of some of these factors are unknown. There is limited information regarding the effects of breeds on CH_4 production. Lal et al. (1987) observed that energy losses as CH_4 were higher in Holstein-Friesian × Harian cross cattle than in Holstein-Friesian cattle in India.

Ruminant CH_4 production has received considerable attention in recent years due to its contribution to atmospheric CH_4. Emissions from ruminants are estimated to contribute 16–20% of global atmospheric CH_4, of which 75% is produced by cattle (Crutzen et al. 1986). Ruminant CH_4 production has in the past been measured using respiration calorimetry from which prediction equations relating CH_4 production to dietary components have been derived (Blaxter and Clapperton 1965; Moe and Tyrrell 1979; Holter and Young 1992). In-vitro techniques (Czerkawski and Breckenridge 1977; Dong et al. 1997) and isotopic methods (Murray et al. 1976; Frances et al. 1993) have also been used. Conditions with the use of respiration chamber, in-vitro techniques, isotopic method and assumptions of prediction equations cannot be related to cattle under production situations, where environmental temperature, meal size and frequency, and selection of feed components can affect intake, rate of digestion and retention time in the rumen. To ensure that appropriate reduction strategies are established for the industry, there is a need to refine CH_4 estimates under normal production conditions.

Recent advances in measurement methods, such as the SF_6 tracer gas technique, which uses an inert tracer gas source placed in the rumen of the animal, allows direct measurement of CH_4 in unrestrained individual animals from samples of gases collected at the mouth and nose (Johnson et al. 1994). This technique does not measure all hindgut CH_4, which accounts for approximately 13% of total methane produced (Murray et al. 1976). However, 89% of hindgut methane is absorbed into the blood stream and expired through the lungs, which can be collected. Thus, the SF_6 tracer gas technique may be able to account for more than 95% of total CH_4 production (Johnson et al. 1994). The SF_6 tracer gas technique has been used on several animals simultaneously in their pens or while they graze (Lassey et al. 1997; McCaughey et al. 1999); however, animals have to be trained to wear a halter and collection canisters.

The objective of this study was to use the SF_6 tracer gas technique to measure and assess variations in CH_4 production in growing dairy and beef breeds being fed different forage at two levels of intake.

MATERIALS AND METHODS

Animals and Management

Six Holstein [Dairy, 310 ± 15.3 kg (mean ± SD)] and six Charolais × Simmental (Beef, 310 ± 10.0 kg) yearling heifers (12 mo) were used in the study to assess the effects of cattle breed type (dairy vs. beef), and forage quality at two levels of feeding on CH_4 production. It was expected that dairy heifers would consume more feed relative to body weight than beef heifers (National Research Council 1996), and this would influence CH_4 production. The experiment was conducted from 3 February 1998 to 24 April 1998 at the University of Manitoba Glenlea Research Station, 20 km south of Winnipeg, Manitoba. Animals were adapted on a grass hay diet for a 2-wk period prior to the start of the trial. During this period, heifers were trained to wear halters with chain suspensions, to adapt them to wearing the CH_4 measuring apparatus later during the trial. Animals were held individually in open fronted pens with attached feeding troughs. Wood shavings were provided as bedding. The heifers were managed according to the guidelines of the Canadian Council on Animal Care.

Feeding

Three hay diets were chosen based on their IVOMD, and designated high-quality (61.5%; legume/grass mixed hay), medium-quality (50.7%; grass hay) and low-quality (38.5%; grass hay) forage (Table 1). We anticipated a dietary effect on CH_4 energy yield during fermentation, because the rate and extent of digestion in the rumen would differ due to differences in digestibility and fibre content. Each hay diet was chopped and fed to four animals (two dairy and two beef heifers) in each period of four 3 × 3 Latin squares.

Each period consisted of 23 d; animals received their respective diets ad libitum (15% orts) for 14 d. During ad-libitum feeding, animals were adapted to their forages for 9 d, before five 24-h CH_4 collections began. Following ad-libitum feeding, DMI of heifers was restricted to 2% BW on the same diet (to ensure all feed was completely consumed) for 9 d, which included a 4-d adjustment period, followed by five 24-h CH_4 collections. A 7-d adaptation was allowed between periods as animals switched diets.

Heifers were fed chopped hay once a day in the morning, and received 50 g Hi C-N-Z (1:1) mineral/vitamins with selenium (Feed-Rite Ltd. Winnipeg, MB) daily as a top dress. Trace-mineralized salt blocks and water were offered ad-libitum. Body weights were measured at the end of the ad libitum and restricted feeding phases of each period to adjust the amount of hay fed accordingly.

Haylots were core-sampled prior to feeding in each period for chemical analyses (Table 1). Chopped hay offered and orts were weighed and sampled daily. Daily feed and ort samples were composited for each feeding level in each period, and sub-sampled for analysis of dry matter (DM).

Methane Gas Sampling and Analyses

Methane gas was sampled using the SF_6 tracer gas technique (Johnson et al. 1994). Stainless steel permeation tubes (12.5 mm × 40 mm) with known release rates for SF_6 were

Table 1. Chemical composition (DM basis) of forage treatments fed to heifers

Treatment Forage type	High Legume/grass	Medium Grass	Low Grass
Organic matter (%)	91.4	90.8	90.8
CP (%)	17.9	12.1	11.1
ADF (%)	31.8	38.7	43.2
NDF (%)	41.8	58.1	68.8
IVOMD (%)	61.5	50.7	38.5
GE (kJ g^{-1})	18.4	18.1	18.1

placed in the rumen per os, a week prior to the start of the experiment. This allowed enough time for the tracer gas to equilibrate in the rumen.

The rate of SF_6 release from the permeation tube is controlled by a permeable Teflon membrane held in place by a stainless-steel Swaglok nut. Each tube was charged with 260–300 mg of SF_6 at liquid nitrogen temperatures, and kept in an incubator at 39°C. Release rates of SF_6 were determined by measuring the weight loss of tubes for 8 wk to establish a steady pre-determined rate. Sulphur hexafluoride release rates ranged from 350 to 700 ng min^{-1}.

Gas exhaled from the nose and mouth was drawn into pre-evacuated (30 mm Hg) stainless steel collection spheres (130-mm diameter), through a 900-mm capillary tubing (128 μm i.d) with an in-line 15-μm filter and flexible nose piece fitted to a halter (McCaughey et al. 1999). The collection spheres were suspended by a neck strap, attached to the halter apparatus with a quick connect fitting. The collection system was designed to deliver half its volume during a 24-h collection, ensuring a uniform collection rate. In each period, 24-h gas samples were collected from each animal for 5 d, at ad-libitum and restricted feeding levels. Heifers were restrained in a chute to remove and replace collection spheres. Gas collection systems were hung on the east and west sides of the pens to collect background air samples, which were used to correct expired gas concentrations.

Collected spheres were checked for pressure to identify blocked or leaking capillary systems to ensure data used represented a complete 24-h period. Spheres were then pressurized to 110 KPa with pure N_2, to prevent sample contamination prior to analysis, and to allow collection of samples for injection of gas samples into the sample loop of a gas chromatograph. A gas chromatograph (Star 3600, Varian, Mississauga, ON) fitted with electron capture and flame ionization detectors was used for determining SF_6 and CH_4, respectively. The gas chromatograph was fitted with a Molecular Sieve 0.5 nm (1800 mm) column and a Poropak QS (1800 mm) column for SF_6 and CH_4, respectively. The column oven temperature was 35°C and nitrogen was used as the carrier gas with a flow rate of 30 mL min^{-1}.

Samples were analyzed in duplicate. Prepared standards were used to standardize the gas chromatograph for SF_6 (20 ppt, Scott-Marrin Inc., Riverside, CA) and CH_4 (100 ppm; Supelco, Mississauga, ON) prior to sample analysis. Daily CH_4 production was calculated as follows (Johnson et al. 1994):

$$CH_4\ (\text{L min}^{-1}) = \text{permeation tubes } SF_6 \text{ release rate } (\text{L min}^{-1}) \times [CH_4]/[SF_6]$$

where $[CH_4]$ and $[SF_6]$ are the concentrations of CH_4 and SF_6 in canisters after background concentrations have been deducted. The concentration of SF_6 was not detectable for two beef and one dairy heifer in periods 2 and 3 and CH_4 production could not be calculated for these animals.

Feed Analyses

Feed and ort samples were dried for 48 h in a forced-draught oven at 60°C for DM determination. Samples were ground using a Wiley mill fitted with a 1-mm screen. Dried samples were analyzed for crude protein (CP) using a Kjeltec 1030 auto analyzer [Tecator Inc., Herndon, VI; (Association of Official Analytical Chemists 1990), method no. 984.13], and ash using method no. 942.05 (Association of Official Analytical Chemists 1990).

Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined using an ANKOM 200 fibre analyzer (Fairport NY), with procedures described by Komarek (1993). Gross energy was determined using a Parr 1241 adiabatic bomb calorimeter. In vitro organic matter digestibility was determined by the method of Tilley and Terry (1963) using bovine inoculum.

Statistical Analyses

Methane production and DMI in each feeding regime were analyzed by least square analyses of variance using GLM in SAS Institute, Inc. (1990) using the model:

$$Y_{ijkl} = \mu + B_i + A_{j\,(i)} + D_k + P_l + (ADP)_{j\,(i)kl} + \varepsilon_{ijkl}$$

where Y_{ijklm} is the trait under consideration; F is the overall mean; B_i is the breed with (I = 1, 2); $A_{j\,(i)}$ is the animals within breed, which was used as the error term to test for breed effect; D_k is hay diets with (k = 1..3); P_l is the period with (l = 1..3); $ADP_{j\,(i)kl}$ is the diet × period × animals within breed, which was used as an error term for the diet and period effect; and ε_{ijklm} is the experimental error term. Means were separated at the 5% level of significance using the probability of differences (PDIFF) option. To compute day-to-day and animal-to-animal variations, Type III expected mean squares were generated for the model in each feeding level, and the coefficient of variation (CV) calculated from root mean squares and means.

RESULTS AND DISCUSSION

Methane production ranged from 115.9 to 399.5 L d^{-1} [mean (SD) 229.0 ± 68.2 L d^{-1}] in the course of the study. Methane energy lost, percent GEI ranged from 4.6 to 9.4% (mean 6.9 ± 1.2%) on ad-libitum feeding, while the range was 5.4 to 11.0% (mean 7.3 ± 1.6%) on restricted feeding. The CH_4 energy yields in the study are comparable to values reported by McCaughey et al. (1997) for grazing steers (4.1–5.2% GEI) and forage-fed heifers (7.2% GEI) (Johnson et al. 1994) using the SF_6 tracer gas method, and also for forage-fed heifers (7.1% GEI) using respiration calorimetry (Johnson et al. 1994).

Table 2. The effects of breed and forage quality on intake and CH_4 production of heifers fed ad-libitum (LS means ± SE)

	Breed			Diet[z]			
	Beef (*n*=4)	Dairy (*n*=5)	*P* value	High (*n*=9)	Medium (*n*=9)	Low (*n*=9)	*P* value
Intake							
DMI (kg d^{-1})	8.4 ± 0.38	8.2 ± 0.34	0.68	9.7 ± 0.23*a*	8.9 ± 23*b*	6.3 ± 0.23*c*	<0.01
DOMI (kg d^{-1})	4.4 ± 0.12	4.1 ± 0.11	0.61	6.0 ± 0.14*a*	4.5 ± 0.14*b*	2.4 ± 0.14*c*	<0.01
GEI (kJ d^{-1})	152.6 ± 1.11	1542 ± 1.01	0.81	185.6 ± 0.56*a*	159.3 ± 0.56*b*	116.2 ± 0.56*c*	<0.01
CH_4 production							
CH_4 (L d^{-1})	258.7 ± 11.89	258.0 ± 10.62	0.97	28.7 ± 13.35*a*	289.8 ± 13.35*a*	203.5 ± 13.35*b*	<0.01
CH_4 (L kg^{-1} DMI)	30.9 ± 1.76	31.7 ± 1.58	0.73	29.4 ± 1.83	32.5 ± 1.83	32.0 ± 1.83	0.46
CH_4 (L kg^{-1} DOMI)	64.5 ± 3.41	65.3 ± 3.05	0.87	47.8 ± 4.02*a*	63.7 ± 4.02*b*	83.2 ± 4.02*c*	<0.01
CH_4 (% GEI)	6.7 ± 0.33	6.7 ± 0.29	0.91	6.0 ± 0.38	7.1 ± 0.38	6.9 ± 0.98	0.14

[z]See table 1.
a–c Means within factors in a row followed by different letters differ ($P < 0.05$).

Table 3. The effects of breed and forage quality on intake and CH_4 production of heifers during restricted feeding (LS means ± SE)

	Breed			Diet[z]			
	Beef (*n*=4)	Dairy (*n*=5)	*P* value	High (*n*=9)	Medium (*n*=9)	Low (*n*=9)	*P* value
Intake							
DMI (kg d^{-1})	6.3 ± 0.20	6.1 ± 0.18	0.58	6.4 ± 0.07*a*	6.1 ± 0.07*b*	6.1 ± 0.07*b*	0.02
DOMI (kg d^{-1})	3.2 ± 0.02	3.1 ± 0.02	0.58	3.9 ± 0.03*a*	3.1 ± 0.03*b*	2.4 ± 0.03*c*	<0.01
GEI (kJ d^{-1})	112.4 ± 0.84	109.9 ± 0.75	0.61	117.5 ± 0.32*a*	107.8 ± 0.32*b*	107.8 ± 0.32*b*	<0.01
CH_4 production							
CH_4 (L d^{-1})	195.8 ± 13.10	213.2 ± 11.72	0.36	224.6 ± 16.19	193.3 ± 16.19	195.6 ± 16.19	0.35
CH_4 (L kg^{-1} DMI)	31.2 ± 1.89	34.6 ± 1.70	0.22	35.1 ± 2.43	31.6 ± 2.43	32.0 ± 2.43	0.56
CH_4 (L kg^{-1} DOMI)	63.3 ± 4.23	71.3 ± 3.79	0.17	56.6 ± 4.99*b*	62.2 ± 4.99*b*	83.1 ± 4.99*a*	0.01
CH_4 (% GEI)	6.9 ± 0.44	7.6 ± 0.39	0.24	7.6 ± 0.53	7.1 ± 0.53	7.1 ± 0.53	0.78

[z]See table 1.
a–b Means within factors in a row followed by different letters differ ($P < 0.05$).

Contrary to expectation, DMI intake and corresponding CH_4 production (L d^{-1}, L CH_4 kg^{-1} DOMI or CH_4, % GEI) were not different ($P > 0.05$) between dairy and beef heifers for the two feeding levels (Tables 2 and 3). There were no breed-by-diet interactions for intake and CH_4 production. This can be attributed in part to similar initial BW, and similar rate of gain ($P > 0.05$) during ad-libitum feeding ($P > 0.05$) for dairy (0.94 ± 0.13 kg d^{-1}) and beef (1.1 ± 0.13 kg d^{-1}) animals. On the other hand, Lal et al. (1987) observed that energy losses as CH_4 were higher in Holstein-Friesian × Harian cross cattle than in Holstein-Friesian cattle in India. This was attributed to the fact that the indigenous dairy cross had a larger gut capacity than the Holstein-Friesian; a result of adaptation to wheat straw-based diets. This resulted in a longer rumen retention time and increased CH_4 production. Galbraith et al. (1998) reported CH_4 losses of 6.6, 5.2 and 3.3% GEI for bison (*Bison bison*), wapiti (*Cervus elaphus*) and white-tail deer (*Odocoilleus virgianus*), respectively, when fed lucerne pellets, with the lowered trend of CH_4 production corresponding with a reduction in retention time with the smaller animals.

With respect to forage quality, daily DMI (kg d^{-1}), DOMI (kg d^{-1}) and GEI (kJ kg^{-1} d^{-1}) at ad libitum declined ($P < 0.05$) as the quality of forage offered declined (Table 2). Methane production (L d^{-1}) for high and medium diets were 27.8 and 29.8% higher, respectively, ($P < 0.05$) than the low diet during ad-libitum feeding. A faster passage rate in the rumen is associated with more digestible forages. This increases intake, resulting in more fermentable substrate in the rumen and therefore higher CH_4 production (Johnson and Johnson 1995; McAllister et al. 1996). In contrast, CH_4 production per kg DOMI (L kg^{-1} DOMI) increased ($P < 0.05$) as the quality of forages decreased (Table 2).

During restricted feeding, DMI was lower by 5%, on the medium and low diets compared to the high diet ($P < 0.05$), while DOMI declined significantly as the quality of forages decreased (Table 3). These changes in intake with diet quality did not result in any differences in CH_4 production (L d^{-1}) during restricted feeding ($P > 0.05$); however, CH_4 kg^{-1} DOMI was higher by 25% for low-quality versus medium- or high-quality diets ($P < 0.05$). Lower fractional CH_4 losses with the high-quality diet can be expected, as the lower proportion of structural carbohydrate content will change the fermentation pattern yielding less CH_4 (Moe and Tyrrell 1979). Similar findings were reported by Varga et al. (1985), who observed decreased CH_4, percent GEI in cattle consuming alfalfa silage (5.8%) as compared to orchardgrass silage (6.3%). They suggested that the higher digestible organic matter content of legumes coupled with a faster rate of passage shifted fermentation against ruminal methanogenesis.

The day-to-day variation and animal-to-animal variations in intake and CH_4 production are shown in Table 4. There was a higher daily variation in DMI when animals were ad-libitum fed (22.5%) than when restricted fed (9.4%), because similar amounts of diets relative to body weight were offered on restricted feeding. A similar trend was observed in animal-to-animal variations. Significant day-to-day variation and animal-to-animal variation for CH_4 production (L d^{-1}) were observed on ad-libitum and restricted feeding ($P < 0.05$). Variation in CH_4 production within individual animals ranged from 6.6% to 35.0% when fed ad libitum, whereas it ranged from 14.4 to 35.0% on restricted intake. A high coefficient of variation was observed for day-to-day (26.9%) and animal-to-animal (26.6%) ad-libitum CH_4 emissions. Blaxter and Clapperton (1965) observed a lower day-to-day variation (CV = 7.5%) and animal-to-animal variation (CV = 8.1%) in CH_4 production by sheep in calorimetry chambers fed similar diets and amounts. The more variable environmental and feeding conditions and the small number of animals used contributed to higher variation in our study.

Day-to-day variation can be related to such factors as DMI, and this was verified for cattle fed on an ad-libitum basis, where CH_4 production was linearly correlated with DMI ($P = 0.0001$; $r = 0.80$). The strong correlation between CH_4 production rates and DMI suggests that DMI was a major determinant of variations in CH_4 emissions, accounting for 64% of the variation. As a result, a significant ($P = 0.0001$) linear regression of DMI on CH_4 production yielded a prediction equation of:

$$CH_4 \text{ (L d}^{-1}\text{)} = 38.92 + 26.44 \text{ (kg) DMI (kg) } (r^2 = 0.60).$$

On restricted feeding, where similar amount of diets were offered, there was a significant ($P = 0.034$) correlation between CH_4 (L d^{-1}) and DMI ($r = 0.40$); however, DMI explained only 16% of daily CH_4 production. Lassey et al. (1997), using the SF_6 technique to measure CH_4 emissions directly from 50 grazing sheep, observed a weak correlation between CH_4 emission rates and DMI ($r = 0.37$), suggesting that DMI was a relatively minor determinant of variation in CH_4 emissions, accounting for only 14% of the variance. They concluded that the intrinsic differences in sheep affected methanogenic response more than intake.

Animal-to-animal variation may be related to DMI, but could also include the eating behaviour of particular animals, variations in diet consumed relative to diet offered (selectivity of animals) and animal-to-animal variations in rumen capacity and rate of passage of digesta (Van Soest 1982). The fact that variations in DMI on ad-libitum and restricted feeding were very different, but yielded similar animal-to-animal variations under both feeding regimes, suggests that rather than DMI, the digestive tract characteristics of the heifers and/or factors related to the SF_6 technique may be the major determinants of CH_4 variations during restricted feeding.

The direct measurement of CH_4 production from individual animals by the SF_6 technique allowed us to identify the least (8.2 ± 1.4%; CV = 17.5%) and most efficient (5.7 ± 1.3%; CV = 22.9%) animals based on CH_4, percent GEI, in the course of the trial. The SF_6 technique, therefore, provides a useful tool in identifying and selecting animals under pastured or confined conditions based on their CH_4 production. However, more animals and sampling times may be needed to reduce variation observed in measurements. The technique cannot quantify CH_4 produced in the hindgut that was lost via the rectum; therefore, adjustments are needed to values to estimate total CH_4 production. The data of Murray et al. (1976) and Johnson et al. (1994) suggest adjustment of values of 2% and 7% for sheep and cattle, respectively.

Table 4. Variations in DMI and CH_4 production of heifers

Parameter	DMI (kg d^{-1})	CH_4 (L d^{-1})	CH_4 (% GEI)
		Day-to-day variation	
Ad-libitum intake			
Mean ± SD	8.3 ± 1.9	257.9 ± 69.5	6.9 ± 1.2
CV (%)	22.5	26.9	17.8
Restricted intake			
Mean ± SD	6.2 ± 0.6	202.0 ± 54.8	7.3 ± 1.6
CV (%)	9.4	27.1	21.5
		Animal-to-animal variation	
Ad-libitum intake			
Mean ± SD	8.3 ± 2.1	257.9 ± 68.6	6.9 ± 1.2
CV (%)	25.1	26.6	17.7
Restricted intake			
Mean ± SD	6.2 ± 0.6	202.0 ± 51.1	7.3 ± 1.6
CV (%)	8.8	25.3	21.5

CONCLUSIONS

The SF_6 tracer technique provided a measure of CH_4 production directly from growing cattle fed various forage diets in a feedlot environment. Not all hindgut CH_4 production can be accounted for using the SF_6 tracer technique. In the study, breed had no effect on enteric CH_4 production; however, low-quality forages increased fractional CH_4 losses during both ad-libitum and restricted feeding. Methane production could be predicted from DMI at ad-libitum feeding with DMI accounting for 64% of daily CH_4 production variations.

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