Methane emission from grazing sheep and cattle

M.J. ULYATT, K.R. LASSEY[1], R.J. MARTIN[1], C.F. WALKER[1] AND I.D. SHELTON

AgResearch, Grasslands Research Centre, Private Bag 11008, Palmerston North, New Zealand.

ABSTRACT

Measurements of methane emissions from individual sheep and dairy cows grazing typical New Zealand perennial ryegrass/white clover dominant pastures are reported. These are the first measurements reported from grazing sheep, and among the first from grazing cattle. The measurement technique, using a marker gas (sulphur hexafluoride), enables emission rates to be determined from analyses of "breath" samples collected while grazing. More than 250 measurements of daily methane emission from 50 sheep (8 months old) were made, with flock-mean emission 18.9±0.8 g/d. Emissions were weakly correlated with feed intake, and they represented a 4.6±0.1% average loss of gross dietary energy. The corresponding mean emission based on 40 measurements of daily emissions from 10 lactating dairy cows was 263±10 g/d, approximately 6.2% of estimated gross energy intake. A notable feature was the large inter-sheep variability in daily methane emission (range 140%) that could not be attributed to variable intake. This would appear to suggest an appreciable diversity of methanogenic response to digestion, and may be significant in the search for strategies to control emissions of this greenhouse gas.

Keywords: methane emission; sheep; cattle; pasture.

INTRODUCTION

As a greenhouse gas methane is second in global importance to carbon dioxide. Its atmospheric concentration has increased 2.5-fold in two centuries due to human activities. Ruminant livestock account for about 15% of the global production of about 550 Tg/year (Anastasi and Simpson, 1993; IPCC, 1995). However, New Zealand's ruminant livestock contribute about 75% of the national methane emission, which on a per capita basis is very high by world standards: a consequence of high ruminant and low human populations.

Methane is generated microbially in the rumen (~ 90%) and large intestine (~ 10%) via "enteric fermentation". The rumen-sourced methane is released through the mouth and nostrils by "eructation", and ~ 90% of the methane from the intestine is routed through the blood stream and lungs to be expired also at the mouth (Murray *et al.*, 1976). Methane emission represents an energy loss to the animal: typically 5-9% of gross dietary energy is lost in this way (Blaxter and Clapperton, 1965). To date all estimates of ruminant methane emission in New Zealand have been by calculation. Lassey *et al.* (1992) estimated total emission to be 1.24 Tg/year based on livestock numbers and an assessed emission of 7.25% of estimated gross energy intake. Ulyatt *et al.* (1992) estimated New Zealand's ruminant methane emission at 1.5 Tg/yr, based on a more detailed scrutiny of the ruminant population by season and by region (pasture type), and on a model of ruminant digestion which requires feed properties as input. Sheep, dairy cattle and beef cattle accounted for 58%, 18% and 21% of the methane respectively.

The work described in this paper uses a new tracer technique (Johnson *et al.* 1994) to measure the methane emission from individual grazing animals. It's purpose is two-fold: to provide a more accurate, measurement-based estimate of total ruminant emission; and, to search for ways to reduce emission and thus improve the efficiency of feed utilisation.

METHODS

The aim was to determine daily methane emission over 5 successive days from each of 50 sheep and 10 dairy cows. The ERUCT (Emissions from Ruminants Using a Calibrated Tracer) technique developed for cattle by Johnson *et al.* (1994) was used, in which a known source of the tracer gas sulphur hexafluoride (SF_6) is placed in the rumen prior to the experiment and each animal's expired breath is sampled and the ratio of methane to SF_6 determined.

A permeation tube of SF_6 was prepared and calibrated for each participating animal and inserted into the rumen *per os* 5 days prior to participation. The rate of SF_6 release was controlled by a permeable Teflon™ membrane held in place by a porous stainless steel frit and locking nut. Each tube was charged at liquid nitrogen temperatures with (500mg ultra-pure SF_6, and weighed weekly for at least 2 months prior to insertion to establish a steady permeation rate at rumen temperature (39°C). Permeation rates were in the range 1.9-3.5 mg SF_6/d.

Each animal was fitted with a halter, to which was attached with Velcro™ straps a yoke-shaped PVC canister which fitted over the neck. An inlet tube was placed over the nose and lead via a capillary tube to the canister. The yoke was pre-evacuated and the rate at which air was sampled from near the animals mouth was determined by the length and diameter of the capillary tube. The capillary

[1] NIWA, P.O. Box 14-901, Kilbirnie, Wellington, New Zealand.

was protected against dust infiltration by a 15µm filter. The yoke was readily isolated and exchanged each day by means of a Nupro™ valve and Swagelok™ quick connect fittings. Yoke volumes were typically 1.7 and 2.5 litres for sheep and cattle respectively, and the capillary system was designed to deliver an integrated sample of half this volume during 24 hours. The animals were acclimatised to wearing the halters for a week prior to their involvement in an experiment. An identical apparatus was placed up wind each day to collect an integrated background air sample.

Upon removal from the host animal, each yoke was checked for pressure and then over-pressured with pure nitrogen to about 1.5 atmospheres, and a corresponding dilution factor calculated. An abnormal initial pressure suggested a blocked or leaking capillary system was examined and remedied with minimal delay.

The over-pressured yokes were analysed for CH_4 and SF_6 by gas chromatography using flame ionisation detection (CH_4) and electron capture detection (SF_6), each against prepared standards. Measured concentrations after dilution were typically in the range 7-70 ppm for CH_4 and either 100-600 ppt (parts per trillion) (sheep) or 10-50 ppt (cows) for SF_6. The methane emission rate (both eructed and expired) was assessed as:

$$Q_{CH4}=Q_{SF6} \times [CH_4]/[SF_6]$$

where $[CH_4]$ and $[SF_6]$ denoted yoke concentrations in excess of background and Q_{SF6} was the rate of SF_6 permeation from the particular tube.

Measurements were conducted in the Manawatu from 17 March to 4 April 1996. Both sheep and cows were grazed perennial ryegrass/white clover dominant pastures and were controlled with electric fences to give one rotation of feed per day. Pasture was managed by initiating a cutting sequence (sheep) or grazing rotation (cows) four weeks before the experiments commenced. Each day the animals were allocated about 2.5 times their expected daily dry matter (DM) intake, so that intake was not limited by pasture availability. All animals were grazed on similar pasture for at least 2 weeks prior to the experiments.

Individual daily emissions were measured for 5 days from a flock of 50 sheep - 8 month old Romney cryptorchids weighing 32.5-44.0 kg (mean 37.0±2.5 kg) and mean weight gain 0.3 kg/d. For logistical reasons, 3 subflocks of 18 were processed on 3 successive weeks, each including two "control sheep" retained for all 3 weeks as indicators of inter-week variation. Each subflock was selected at random from the available sheep. The control sheep, selected during week 1 on the basis of consistency of methane production and of temperament, were also monitored over the intervening weekends. This sampling protocol allowed up to 278 sheep-days of data, including two 19-day time series.

The dairy cow herd, 10 Friesians weighing 402-562 kg (mean 483±14 kg) and mean liveweight gain 0.5 kg/d (7d period), were processed concurrently with the sheep subflock of Week 2. Milk production was 12.0-16.4 kg/d (mean 14.0±0.7 kg/d) corresponding to approximately 210 days of lactation.

Feed intake was estimated by different methods for the sheep and cows. Each sheep was trained to wear a harness and faeces collection bag through the methane collection period. Faeces were collected twice a day, weighed and subsampled for subsequent chemical analysis. Samples of pasture were collected before the new rotation each morning by hand-cutting to estimated grazing height. These samples were dried, bulked and used to determine chemical composition and *in vitro* digestibility by NIR spectrometry. Dry matter intake (DMI) was calculated from faecal DM output and *in vitro* DM digestibility. Estimation of cow DMI proved more problematic. Deployment of a chromic oxide marker from a slow release device (Captec™; Nufarm) lead to extreme fluctuations in faecal chromium concentration and unrealistic estimates of faecal DM output. As an alternative DMI was calculated from measured liveweight, liveweight change and milk production over a week using a model of cow nutrient requirements (FeedTECH; D. McCall, M. Ulyatt, unpublished).

RESULTS AND DISCUSSION

Sheep measurements

There was considerable variation in the degree of dilution of expired gases by local background air during methane collection. High dilution can compromise the precision of estimation of emission rates. The main determinant appeared to be geometry of the inlet tubing at the nose rather than prevailing weather conditions, though there was greater variability on windy days. Methane concentrations as collected were 95% in the range 21-210ppm. Methane emission estimates follow reliably from such concentrations. In total 258 out of a possible 278 collection days (95%) were completed. Four of the lost days occurred when one sheep died and the remainder were due to apparatus failures due to water intrusion into the capillary system.

Feed composition for both the sheep and cattle measurement periods is given in Table 1. There was no significant difference in composition between the three sheep weeks. The cattle pasture was of slightly better quality in terms of lower fibre, and higher soluble carbohydrate and *in vitro* digestibility.

TABLE 1: Feed composition (% DM) determined by Near-Infrared Reflectance Spectrometry (NIR) for the sheep and cattle measurement periods.

Component	Week (sheep)			Dairy
	1	2	3	Cows
Crude protein	24.7	23.6	26.5	25.4
Acid detergent fibre	24.4	25.2	24.0	22.2
Neutral detergent fibre	43.5	44.9	44.9	41.4
Soluble carbohydrate	7.5	8.1	6.8	10.8
Lipid	4.1	4.1	4.5	4.4
Ash	9.9	10.0	11.3	10.7
In vitro digestibility	75.4	74.7	75.8	77.3

Data on methane emission and DMI (Table 2) were analysed using a cluster formalism (Kendall and Stuart, 1968) where each sheep within a week was viewed as a cluster of up to five samples (sheep days). Variance within the week mean was segregated into two components: intra-cluster (day to day variation within each sheep) and inter-cluster (inter-sheep variation). The variances were dominated by inter-sheep variation, which accounted for 82, 94 and 88% of the variance for weeks 1 to 3 respectively. Methane emission (g/d) was significantly higher in week 3 than in week 1. There was no significant difference between weeks in DMI or methane emission per unit of DMI.

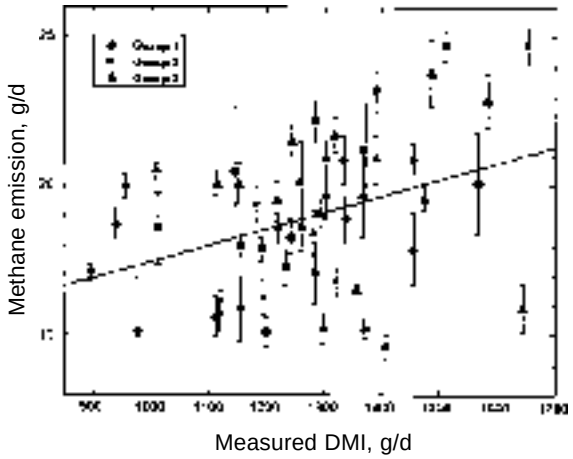
A feature of the data was the large differences between animals in methane emission (range 14.6-33.0 g/d). This was only partly due to a wide range in DMI (895-1652 g/d) as is highlighted in Fig. 1. Emission was only weakly correlated with DMI (r^2=0.14) suggesting that DMI was a relatively minor determinant of variation in methane emission. Indeed, for mid-range DMI (1400 g/d) methane emissions ranged from 14.6 to 23.8 g/d, with the four highest emitters 40% higher on average than the lowest four (16.0±0.7 vs 22.5±0.6 g/d). Blaxter and Clapperton (1965) noted a similar large variation in methane emission in sheep given the same DMI.

TABLE 2: Methane emission and dry matter intake data (± s.d.) from three subgroups of sheep measured on three successive weeks.

Week	1	2	3	Mean
No. Sheep	16	18	18	
CH_4 emission (g/d)	17.7±0.6^a	19.0±0.8^{ab}	20.1±0.5^b	18.9±0.8
DMI (g/d)	1214±44	1264±41	1334±38	1271±42
CH_4/DMI (mg/g)	14.9±0.7	15.2±0.5	15.3±0.5	15.1±0.4

Means with different superscripts were statistically different (P<0.01)

FIGURE 1: The relationship between individual animal methane emission and dry matter intake in sheep measured over three successive weeks (Groups 1, 2 and 3). Error bars denote one standard deviation in mean emission based on up to 5 daily measurement per sheep. A linear regression (r=0.37) was fitted to the total data.



Dairy cows

A total of 40 cow-days of breath samples were collected from the 10 cows. This represented an 87% success rate, given that one cow was removed from the experiment after one day because of a health problem. Mean emission rate for the cows was 263 ± 10 g/d. DMI was estimated to average 12.88±0.24 kg/d and methane emission per unit of DMI was estimated as 20.94 g/kg, a figure about one third higher than that for sheep (Table 2). However, the method used to calculate intake for sheep was more robust than that used for cattle. There was also a weak positive correlation between DMI and methane emission in cows (r^2=0.52). As with the sheep, inter-animal variation was the main source of variance in methane emission (87%).

General

Methane yield is often expressed as the percentage of energy intake lost as methane. Methane yield averaged 4.57 ± 0.10% for sheep and 6.16±0.15% for dairy cows. The value for sheep was at the low end of the range (5-9%) commonly cited in the literature (Gibbs *et al.* 1989), while that for dairy cows was close to the mean. Methane yield correlates negatively with DMI (Blaxter & Clapperton, 1965; Gibbs *et al.* 1989) and this was the case with sheep (r=-0.60), but not cattle (r=0.22). Lower methane yields at high intakes are presumably a reflection of faster rumen clearance and thus proportionately lower rumen digestion of feed residues.

The extent of the variation in daily methane emission from sheep and cattle that was independent of feed intakes (> 80% of variance) was unexpected. If this result is substantiated by further work it raises the prospect of developing natural and cost effective methods, either through animal selection or rumen microbial manipulation, of reducing methane emission from livestock in New Zealand. This could satisfy the dual goal of reducing the adverse environmental impact of ruminants and increasing animal efficiency.

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